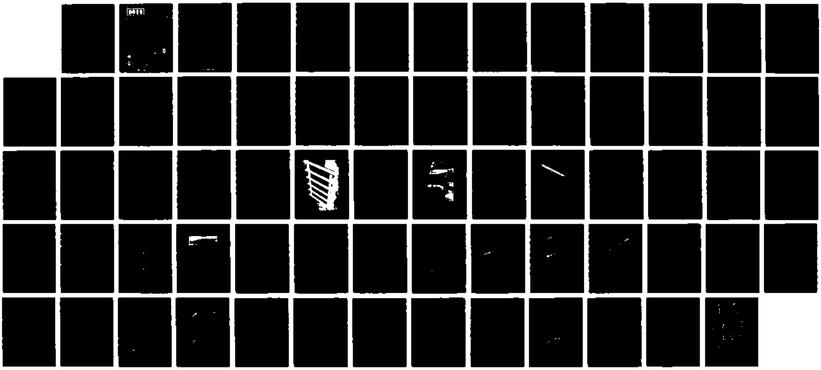
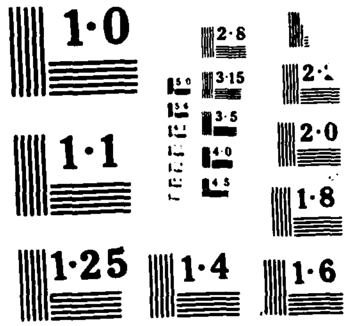
AD-A190 989 STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE(U) DEFENCE RESEARCH ESTABLISHMENT SUFFIELD RALSTON (ALBERTA) J E SLATER ET AL. JAN 88 DRES-485 1/1

UNCLASSIFIED F/G 13/10 NL




1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·8
3·15
3·5
4·0
4·5

National Defence / Défense nationale

UNCLASSIFIED

DRES

SUFFIELD REPORT

NO. 485

STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE (U)

by

J.E. Slater, R. Houlston

and

D.V. Ritzel

PCN No. 0113R

January 1988

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD, RALSTON, ALBERTA

UNCLASSIFIED

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON ALBERTA

SUFFIELD REPORT NO. 485

STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE (U)

by

J.E. Slater, R. Houlston
and
D.V. Ritzel

PCN No. 0113R

Task No. DMES-26

UNCLASSIFIED

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON ALBERTA

SUFFIELD REPORT NO. 485

STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE (U)

by

J.E. Slater, R. Houlston
and
D.V. Ritzel

ABSTRACT

Modern computational methods and experimental test procedures are being developed to determine more accurately the air-blast loading and dynamic response of naval ship structures subjected to weapon explosions. Previously, a series of air-blast trials on full-scale stiffened panels typical of those used in warship superstructures had been conducted for conventional scale weapons (under 454 kg HE) to evaluate new design and damage-assessment techniques. The present report describes the experimental results and the associated numerical study of the panel response for a longer duration loading generated by the simulation of a 8 kiloton nuclear weapon surface explosion called MINOR SCALE. The panel, exposed to a side-on overpressure blast loading of 345 kPa peak and 200 ms positive duration, experienced only slight permanent deformation of about 25 mm with no apparent weld or buckling failure. The measured pressure, strain, acceleration and displacement data correlated well with the computed numerical results, thus verifying the computational methods.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the ADINA analyses carried out by Mr. C. DesRochers at MARTEC Ltd. Also special thanks to Messrs. G. Rude of the Shock and Blast Group, and R. Campbell and D. Saint of the Electronic Design and Instrumentation Group at DRES for their assistance with the experiment; and to Mr. C. Workman for processing the data while working for the Shock and Blast Group as a COOP student under the supervision of Dr. R. Houlston.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON ALBERTA

SUFFIELD REPORT NO. 485

STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE (U)

by

J.E. Slater, R. Houlston
and
D.V. Ritzel

1. INTRODUCTION

In the design of naval ships, a capability to assess the dynamic response and damage of structures subjected to impulsive loads from external or internal air-blasts and underwater explosions is required not only for the purpose of blast-hardening the design, but also for accurate prediction of the mechanism of failure and the extent of damage once design thresholds are exceeded. For these types of explosions, the vulnerability and combat readiness of the complete ship structure must be assessed. The Canadian DND currently has procedures for design of naval ship structures against blast and shock loading some of which are based on theoretical and empirical approaches used for decades. The Defence Research Establishment Suffield (DRES) is developing modern computational methods and experimental test procedures for more accurate determination of blast and shock loading and structural response in order to upgrade and facilitate design analyses.

Metal plates and panels are fundamental elements in many military structures; particularly ships which are composed primarily of stiffened metal panels that make up the hull, decks, bulkheads and superstructure. The panels must be designed to withstand air-blasts from either conventional or nuclear weapon explosions. In regard to this subject, DRES has been tasked by the Director Maritime Engineering and Maintenance (DMEM) and Director Maritime Engineering Support (DMES) to conduct a series of air-blast trials on full-scale stiffened panels typical of those used in warship superstructures in order to evaluate new design and damage-assessment techniques being developed as part of the Shock and Blast research program at DRES (Project Number 011SA — "Methods for Warship Design to Withstand Blast and Shock"). This research complements and extends DRES's previous experimental and analytical studies on the effects of air blast on masts and antennas, which were conducted in the 1960's to mid 1970's.

The panel tests at the DRES Height-of-Burst (HOB) experimental range facility were limited to blasts from conventional scale weapons (under 454 kg HE) giving loads in the impulsive realm with relatively short time duration. The experimental data from a series of tests on square plates, and the correlation with numerical results from the finite element code ADINA have been presented in References 1 – 6, and a comprehensive summary of the experimental results from tests on a stiffened panel is given in Reference 7.

The present report describes a study of the response of stiffened panel structures to longer duration loading typical of that generated by nuclear weapon explosions. On 27 June 1985, the U.S. Defense Nuclear Agency (DNA) conducted a ground burst simulation of an 8 kiloton nuclear explosion called MINOR SCALE at their Permanent High Explosion Test Site (PHETS), White Sands Missile Range (WSMR), New Mexico. For that test, an experiment was fielded to measure the response and damage of a full-scale stiffened panel subjected to a blast loading of 345 kPa (50 psi) peak overpressure and 200 ms positive duration. The panel survived the blast loading, experiencing only slight permanent deformation of about 25 mm. The test results and preliminary numerical correlations were reported at the MINOR SCALE symposium held in February 1986 [8]. The present report contains a comprehensive presentation of the experimental data, a description of the computational methods, and correlation of the test data and numerical results.

2. OBJECTIVES

To fill the technology gap on the response of ship stiffened panel structures to long duration air blasts, a panel was fielded at the 8-kt nuclear ground-burst simulation MINOR SCALE. The project was undertaken in response to a requirement by DMES under Task DMES 26. The objectives of the project were as follows:

1. Conduct measurements of the blast loading and structural response on a full-scale ship's stiffened panel subjected to a long duration, air-blast overpressure pulse of sufficient strength to produce permanent plastic deformation.
2. Establish the pattern and mechanism of failure and the loading function necessary to cause failure.
3. Correlate the loading and response measurements with design analysis computational methods.

Thus, with results and insight gained from the experimental data and application of the theoretical and numerical analyses, the overall objective is to develop and validate new design and damage-assessment techniques for ship panel structures subjected to long duration air-blast loading typical of nuclear weapon explosions.

3. EXPERIMENT DESCRIPTION

At event MINOR SCALE, 4.8 kilotons of Ammonium Nitrate-Fuel Oil (ANFO) explosive material in a hemispherical fibreglass container was detonated to generate the shock overpressure loading equivalent to an 8 kiloton nuclear explosion. The full-scale stiffened steel panel fielded at MINOR SCALE was identical in structural design to the panels tested at DRES (see Figure 1). The effective size of the Tee-beam stiffened panel was 2.44 m × 4.57 m with 6.35 mm plating (see Figure 2). The panel was mounted flush with the ground surface at a radial location 278 m from ground zero to provide a blast loading of 345 kPa peak side-on overpressure and 200 ms positive duration. With 203 × 203 × 50 mm sections welded to the 152 × 152 mm box-beam perimeter structure, the panel was embedded in a reinforced concrete foundation to simulate rigidly clamped boundary conditions. Photographs of the foundation and panel site during and after the panel installation are shown in Figure 3. Access to the underside of the panel via a hatch cover and crawl space was provided to allow for attachment of transducer sensors and hook-up of cables.

As shown in Figure 2, the panel was instrumented at various locations with transducers for measuring the side-on overpressure, the resulting vertical displacement and acceleration of the panel, and the strain on the panel surfaces. The strain was monitored 40 mm from the beam and outer boundary edges. In addition to the panel instrumentation, two DRES blast gauges [9, 10] were located at either end of the panel (Figure 3(b)) to measure the free-field blast-wave characteristics: static and stagnation overpressure, shock speed, and density. The transducer analog signals from the panel were cabled to an instrumentation bunker, and recorded on magnetic tape for later digitization and data processing. Following the blast, the panel was examined and surveyed to determine the shape of the deformed surface and the extent of the damage.

4. COMPUTATIONAL METHODS

An important objective of the project was to correlate the blast loading and structural response measurements with numerical predictions. This section will describe the various computational methods that have been developed or are available at DRES.

4.1 Blast Loading

For the blast loading at MINOR SCALE, the location and orientation of the panel flush with the ground reduced the loading to a simple side-on overpressure of 345 kPa peak and 200 ms positive duration. The loading was essentially spatially uniform over the panel surface due to the long duration of the blast wave except for the initial passage of the shock front across the panel.

There are various methods available for describing the time history of the side-on overpressure. Baker *et al.* [11, 12] provide simplified methods for representing the pressure time-history. For the positive phase only, a simple exponential equation of the form

$$P(t) = P_s e^{(-k_a t / T_d)} \qquad (1)$$

where P_s is the peak overpressure, b_o the decay constant, and T_d the positive duration is generally adequate. As an improvement, the modified Friedlander equation

$$P(t) = P_s(1 - t/T_d)\, e^{(-bt/T_d)} \qquad (2)$$

has been developed [13]. This functional form gives a reasonable fit to experimental data for the positive phase and the negative phase up to a time $t = 1.5\, T_d$.

For structural response analysis using finite element codes, it is advantageous to have a computerized procedure for automatically generating pressure loads resulting from a specified explosion. MARTEC Ltd. computerized Glasstone's time functional descriptions [14] of air-blast loading on simple 2-D and 3-D structures, including flat panels, vertical walls, semicylindrical arches and closed 'box-like' objects. Tabulated values of the dimensionless air-blast parameters (except for the decay constant b) in Equation (2) were obtained from Reference 15. The data for the decay constant were extracted from Reference 11. The air-blast loading program developed by MARTEC is described in Reference 16.

More sophisticated computerized methods that have been developed for blast loading predictions include the UVIC Air Blast Compendium [17], the Flux Corrected Transport (FCT) Method [18] and the HULL code [19]. The Compendium generates time functional loading from curve-fits to experimental blast data using the Random Choice Method (RCM) [20]. The FCT and HULL codes determine the blast loading by solving the theoretical equations describing the unsteady compressible inviscid fluid flow.

Results from these various methods will be presented in the next section. Comparisons with the experimental results are given in Section 7.

4.2 Structural Response

Numerous analytical and numerical methods have been developed to analyze the static and dynamic response of structures subject to various types of loadings. Various finite difference and finite element algorithms have been coded for predicting the static and dynamic, elasto-plastic, large deflection behaviour of beams, plates and stiffened panels [21, 22]. For linear and nonlinear response analyses, the finite element codes

VAST [23] and ADINA [24] have been used at DRES. The code VAST, a linear code developed by MARTEC Ltd., has an extensive finite element library, pre- and post-processors for modelling and plotting purposes [25], and a multi-level substructuring/superelement dynamic analysis capability. Special programs have been developed to automatically generate the finite element model of a stiffened panel structure [26] and to describe the time history of the pressure loading [16]. Translators [27, 28] have also been written to interface ADINA with the suite of VAST programs for an enhanced analysis capability [29]. Gross deformations involving both material and geometric nonlinearities can be handled by ADINA.

The basic approach in any nonlinear structural analysis is to initially conduct linear analyses to establish a suitable finite element model representation of the structure and determine the elastic response behaviour. Various finite element models can be generated automatically using the VAST pre-processing program. Static analyses can then be performed to refine the mesh. Natural frequencies and corresponding mode shapes can be calculated using either direct or subspace iteration. Dynamic elastic response analyses is generally performed using direct integration rather than modal superposition because of the impulsive nature of air-blast shock loading. Based on the results of the VAST linear elastic analysis, structural response can then be analyzed with ADINA to predict nonlinear static yielding and deformation, and the dynamic behaviour leading to the final deformation.

Other numerical computational methods have also been developed for response analyses of structures subject to blast loading. Olson and Anderson at the University of British Columbia have developed a finite element code FENTAB [22] for beam modelling, and applied the finite strip technique [30] to simplify the response analysis of stiffened and unstiffened panel structures [31, 32]. These methods reduce the computational requirements substantially; thus making them effective for preliminary design analyses and predictions. The finite element code DRESDYN, developed by Hansen and Heppler at UTIAS has been tailored for response analysis of shell/plate structures exposed to a nuclear blast and thermal environment [33, 34]. The radiant thermal energy effect is represented in the form of a temperature distribution initially applied to the finite element model. The response of the structure subjected to the pressure-time history is then analyzed.

Structural response predictions using the VAST and ADINA finite element programs will be presented in the next section. Final numerical results from ADINA as well as the UBC finite element and finite strip codes will be compared with experimental data in Section 7.

5. PRETEST DATA

Prior to the MINOR SCALE event, the response and damage of the stiffened panel were predicted based on experimental data and analyses from the panel tests conducted at DRES and finite element numerical calculations. The DRES test data were vital for estimating the transducer response levels, understanding the possible modes and mechanisms of failure, and validating of the finite element ADINA code for structural analyses of the panel structures subjected to air-blast loading.

5.1 DRES Panel Data and Analyses

A series of air-blast response trials of a stiffened panel (shown in Figure 1) had been conducted at the DRES Height-of-Burst facility. The charge weight and stand-off height were varied, as summarized in Table 1, to investigate both the linear elastic response and the nonlinear plastic behaviour of the panel. The positive duration of the blast-wave was generally less than one third the panel fundamental period (24 ms) so that the loading was of an impulsive nature.

The first trial (No. 311) was a "twang" test to check procedures and instrumentation. The next two trials (No. 312 and 313) provided elastic structural response data. Trial No. 313 was just below yield with maximum dynamic strain levels approximately twice the static yield value. The fourth trial (No. 314) took the panel just above yield with measured strain levels of 4000 $\mu\varepsilon$ and maximum permanent deformation of about 25 mm. To achieve an even higher blast loading, two 94 kg charges were detonated in the fifth trial. This final shot, which provided a peak reflected overpressure of 6375 kPa, produced substantial plastic deformation as shown in Figure 4. Measured permanent deformation at the midspan of the stiffeners was about 90 mm and the center panel deformed an additional 15 mm. Maximum dynamic deflections and strains were approximately 125 mm and 6200 $\mu\varepsilon$, respectively. The large deflections resulted in substantial membrane stresses being developed in the plating. However, no visible cracking or weld failure was observed.

The fundamental natural frequency was observed to be about 41 Hz (period 24 ms) corresponding to the natural resonance of a single clamped panel segment. At event MINOR SCALE the duration of the shock wave was expected to be about 200 ms, so that the response of the panel would be in the dynamic realm. Based on the DRES panel results, particularly trial number 314, it was anticipated that the MINOR SCALE panel with a peak overpressure of 345 kPa would experience initial plastic deformation of about 50 mm followed by elastic resonance vibrations and a final permanent deflection of the order of 25 mm. The maximum strains and accelerations were predicted to be about 4000 $\mu\varepsilon$ and 2000 G, respectively.

Following the panel trials at DRES, various linear and nonlinear analyses were conducted to validate the finite element codes VAST and ADINA for structural response to the blast wave loading. These analyses required tensile tests at quasi-static and low strain rates to obtain the mechanical properties of the panel material. The following values of static material properties were measured: Young's Modulus = 207 GPa (30×10^6 psi); Poisson's Ratio = 0.3; Yield Stress = 310 MPa (45 ksi); Tangent Modulus = 1230 MPa (178×10^3 psi); Ultimate Tensile Stress (at $\varepsilon = 0.2$) = 565 MPa (82 ksi). The mass density was taken as 7770 kg/m^3. For an anticipated strain rate of 1.2 s^{-1}, the dynamic Yield Stress and Ultimate Tensile Stress values were determined to be 375 MPa (54.4 ksi) and 620 MPa (90 ksi), respectively. The VAST and ADINA structural results have been correlated with the test data and reported in References 1 – 5. For the short duration type of blast loading at DRES and for moderate deformation of the panel, good agreement was obtained between the predicted and observed panel motion.

5.2 Preliminary Predictions

Based on the above calculations, linear and nonlinear analyses were conducted to obtain more accurate predictions of the dynamic response expected at MINOR SCALE. The results of these calculations were used for finalizing the design of the experiment and for setting the transducer signal conditioning and amplifier gain to give optimum range for the transducer sensitivity and recording.

Using the finite element model shown in Figure 5 for a portion of the stiffened panel, nonlinear static ADINA analyses [35] were performed (see Figure 6). Compared to the linear results, the nonlinear geometry and material effects (i.e., large displacement and plasticity) substantially alter the predicted displacement. The nonlinear stiffening effect due to membrane stresses is apparent even at low levels of loading; and at 210 kPa, yielding of the material becomes significant. Based on the nonlinear material ADINA static analysis, the final deflection of the panel for an overpressure of 345 kPa was then estimated to be about 50 mm with maximum displacements during the first few cycles of motion being as large as 100 mm.

Calculations were also undertaken to predict the time history of the dynamic response behaviour of the panel. The expected pressure-time history loading on the panel predicted by the simplified method (Equation 2) of Baker *et al.* [11, 12] and the MARTEC computerized method [16] were used for selecting the site of the panel. More detailed prediction of the expected pressure loading at MINOR SCALE was provided by S - Cubed Inc. using the HULL code [19]. Figure 7 shows the predicted pressure-time history at a location near the panel site. The amplitude was scaled to obtain a pressure-time curve with a peak overpressure of 345 kPa. The positive impulse was predicted to be 15.9 MPa-ms.

Using the loading data provided by S-cubed as input to ADINA, the dynamic response of the panel was computed for the first 40 ms. The displacement-time histories predicted at the center of the panel (node 289, transducer D 12) and at the midspan of the beam (node 303, transducer D 13) are shown in Figure 8. The initial elasto-plastic deformation due to arrival of the shock front was predicted to be – 75 mm for the panel and – 50 mm for the beam. This was followed by elastic vibration at 110 Hz (9 ms period) which tended to approach final deflection values of about – 45 mm for the panel and – 35 mm for the beam.

The acceleration-time histories predicted for accelerometers A 2 and A 3 located at positions D 12 and D 13, respectively, are shown in Figure 9. The initial negative acceleration was expected to be about 900 G, with a subsequent positive acceleration about 1600 G for the panel and 1200 G for the beam. The prediction for acceleration A 7 at node 145 was similar to A 2.

At the time of the calculations, the time history for the components of stress rather than strain was available from the ADINA output. Because plastic deformation of the panel was expected, the stress could not be directly converted to strain. For the purpose of setting-up the strain amplifiers, the ADINA stress predictions and the strain measurements from the previous DRES trials were considered quite adequate. The dynamic stress predictions were converted to strain using Young's Modulus for the elastic portion and Tangent Modulus to account for plastic yielding. Strain levels of the order of 4000 $\mu\varepsilon$ were predicted on the upper surface due to combined bending and membrane effects.

6. EXPERIMENTAL RESULTS

Immediately after the MINOR SCALE Event, preliminary plots of all transducer signals were generated to determine what test data were successful recorded and to provide data for the 'quick-look' report. The panel was examined to assess the extent of damage. The final deformed shape was measured using a precision survey level. Subsequently, the recorded time history data for pressure, displacement, acceleration and strain were digitized. The computer program SPADE [36] was used to correct the signal baseline, apply the calibration factors, and remove any extraneous noise signals. This program was also used to integrate the acceleration to obtain velocity and displacement, average the pressure-time history traces, and to produce time history plots.

6.1 Blast Loading

Figure 10 shows the pressure-time histories recorded by transducers P 1, P 2 and P 3 located at the panel surface and P 8 at a blast gauge station [9] near the panel. The inserts show the initial 50 ms of the pressure pulses. These pulses have some unexpected perturbations which could be attributed to ground surface roughness and boundary layer effects, local anomalies in the shock front, ground/panel surface discontinuity or strain gauge cable obstruction near the pressure transducers. The peak overpressure was approximately 345 kPa (50 psi), with a positive impulse of 15.7 MPa-ms and a positive duration of 200 ms. At 750 ms, a secondary shock characteristic of blast waves for high explosives is evident.

As evident from the inserts in Figure 10, there are differences in arrival time of the shock front at the various transducer locations. In this figure, zero time is chosen as the average of the arrival times at the four transducers. The differences in arrival times is partially due to the velocity of the shock wave across the panel. The shock wave transit time from the front to back edge of the panel is about 3 ms. However, correlation of the shock arrival times from all transducers (reported in Reference 9) shows that there is evidence that the incident shock front was distorted in shape at this site location. Over a span of the panel site, the shock front had an inflected curvature and was obliquely incident by as much as 28 degrees from the expected radial propagation. Since there is no above-ground structures within 100 m of this site, a possible explanation for this disturbance is a reflection from a road and ditch alongside the panel site. The road had a hard-packed gravel surface causing slightly higher shock velocity and the ditch was about 0.7 m deep by 2 m wide. Both ran parallel to the blast radial line and came within about 3 m from the panel site.

Although some aspects of the blast flow arrival times appear irregular, these irregularities should not strongly affect the panel response. Thus, for structural analyses purposes, the arrival times of the four signals were synchronized and the amplitudes averaged to generate the representative pressure-time history shown in Figure 11. This averaged pressure curve was used as the applied load in the final numerical analyses performed by MARTEC (Section 7.2).

6.2 Structural Response

The displacement-time histories measured by transducers D 12 and D 13 (see Figure 2) for the panel center and beam midspan, respectively, are shown in Figure 12. The initial deflection is approximately −53 mm for the panel and −30 mm for the beam, followed by elastic oscillations about a mean that shows some recovery until the arrival of the second shock. It is important to note that the recovery of the mean deflection follows a shape similar to the exponential like decay of the blast load amplitude (Figure 11). This in inherently related to the long duration of the MINOR SCALE blast wave. The final (permanent) deflection is approximately −25 mm for the panel and −16 mm for the beam; corresponding closely with the post-shot survey measurements of −25 mm and −15 mm for the panel and beam, respectively. A photograph of the panel structure and a diagram of the final shape of the panel surface (magnified by a factor of 10) are presented in Figure 13. Values for the permanent deflections at the panel centers and beam midpoints are included in this figure.

The accelerations measured by the various accelerometers are presented in Figures 14 and 15. The accelerations A 1 and A 3 at the midspan of the beams are very similar. When the traces of A 2 and A 3 are plotted together the increased motion of the panel center compared to the beam midspan can be clearly seen. Accelerations recorded at the other points on the panel are similar to that at A 2. The combined plots in Figure 15 indicate time delays in the various traces due to the transit time of the shock front across the panel (about 3 ms) as well as the additional time difference caused by the local oblique flow anomaly in the shock front previously discussed.

By integrating the acceleration twice, the displacement motion is obtained. Figure 16 shows the resulting displacement-time histories at various points on the panel. In the upper two plots for the panel center and beam midspan, respectively, the integrated displacements are compared with the traces measured directly with the displacement transducers. Excellent agreement is obtained in both cases, confirming the accuracy of the displacement obtained from double integration of the acceleration. Displacements at the center of the adjacent panel segments given by A 4 and A 5 are similar in level to A 2, but A 5 exhibits slightly more elastic vibration, being near the panel edge.

Plots of various measured strain-time histories are presented in Figures 17 – 19. No data were available from S 15, S 17, S 21 and S 25 because of gauge failure. The strain measurements on the upper and lower surfaces shown in Figure 17 illustrate the tensile and compressive bending strains, and the presence of an in-plane membrane strain corresponding to the difference between the two signals. The strain signals presented in Figures 18 and 19 show the consistency obtained across the panel, and the relative levels of the strain normal and tangential to the panel edge about 40 mm from the boundary. In the bottom diagram of Figure 19, the initial signals from strain gauges S 18 and S 20 arrive at slightly different times (about 3 ms) due to the transit time of the shock front across the panel. Peak strain levels of the order of 3500 $\mu\varepsilon$ were measured by the gauges on the upper surface due to combined bending and membrane effects. Along the actual lines of attachment of the plating to the beam stiffeners and outer boundary edges, even higher levels of strain are anticipated due to plastic hinge effects. The initial strain rate calculated from the plots ranges from 0.76 s^{-1} to 1.9 s^{-1} which spans the anticipated value of 1.2 s^{-1} used to determine the material properties in the pretest finite element analysis (see Section 5.2).

7. NUMERICAL RESULTS AND CORRELATIONS

7.1 Blast Loading

Since the dynamic response of the panel structure depends on the loading function, the measured pressure-time history was employed for the final numerical calculations. Although the finite element code can incorporate the transit time of the shock front over the panel and any other spatial variations, the analysis was simplified by assuming that the pressure load was applied instantaneously and that it was spatially uniform over the panel surface. The pressure-time history (shown in Figure 11) was generated by synchronizing and averaging the amplitudes of the actual measured pressure traces. The averaged loading data agree well with the HULL code predictions (Figure 7) except for the perturbations in the initial waveform between 2 to 14 ms. As will be evident by the following results, the perturbations in the initial waveform do affect the dynamic response and vibrational characteristics of the panel structure.

7.2 Finite Element (ADINA) Results (MARTEC)

Using the ADINA code and a refined finite element model (Figure 20), MARTEC [37] re-calculated the displacement and acceleration at the center of the panel (node 457, transducers D 12 and A 2) and at the midspan of the beam (node 472, transducers D 13 and A 3) (see Figures 21 and 22, respectively). As shown in Figure 21, the initial elasto-plastic deformations are now determined to be −48 mm for the panel and −28 mm for the beam; about 40% smaller than the preliminary predictions (see Figure 8) based on the HULL code predicted loading. The reduction in maximum dynamic displacements is a result of the reduced effective loading due to the perturbations in the actual shock wave between 2 − 14 ms. By projecting the curves to later times, it appears that the permanent deflections approach about −25 mm for the panel and −15 mm for the beam, corresponding closely with the measured deformations of the panel (−25 mm) and beam (−16 mm) shown in Figures 12 and 13. The acceleration-time history for accelerometer A 2 (Figure 22) has a range (−900 G to 1600 G) similar to the preliminary predictions (see Figure 9), but the acceleration at A 3 on the beam has a range (−500 G to 800 G) which is somewhat less than that originally predicted.

Further comparison of the ADINA numerical results with the experimental motion data shows good agreement (Figures 23 and 24). The measured and predicted acceleration and displacement at the panel center and beam midspan have similar levels and waveform. The initial plastic deformations occur within the first 6 ms of the applied shock wave loading and peak deflections occur within one period (24 ms). The experimental data also exhibit some higher frequency vibrational characteristics due to harmonic vibrations and/or transverse wave vibrations in the plating. Some of these vibrations could also be extraneous noise generated by transducer ringing, and/or vibration.

7.3 Finite Element (ADINA) Results (DRES)

Correlation of the numerical predictions with the experimental data depends of the accuracy of the finite element model and the loading function. The size of the time step for numerical integration and the interpolation procedures and convergence criteria are also important.

Using the latest version of ADINA (1984), further analyses were conducted by refining the model, extending the numerical calculations to 1000 ms and producing strain-time history results for direct correlation with the experimentally measured data. The new finite element model (Figure 25) was developed using the 4-node quadrilateral plate/shell element. An extended pressure curve obtained by averaging transducers P 1 and P 3 was used as the pressure loading (Figure 26).

The excellent correlation of the displacement results for the panel center well beyond the second shock is shown in Figure 27. The prediction of too large a final beam deflection is due to over stiffness of the finite element model for the beam after plastic deformation and the lateral membrane restraint for the remainder of the panel. Modelling one quarter of the complete panel and refining the model with more elements through the web height and across the flange would reduce the stiffness and improve the displacement predictions during the recovery phase of the panel deflection.

The numerical results for strain-time history are determined at the gauss integration points of the nearest finite elements and then interpolated to strain gauge locations. Correlation of the strain-time histories for a number of the gauges are shown in Figures 28 – 30. Numerical results for S 15 and S 17 are included in Figure 28 even though no experimental data were available because of gauge failure at these locations.

The difference in start time between the predicted and measured strain-time histories in Figures 29 and 30, is simply due to the sweep time of the shock front over the panel relative to the synchronized and averaged time of the loading function used for the analyses.

7.4 Structural Response (UBC)

Numerical results for the panel motions were also obtained using newly developed finite element and finite strip codes. The finite element equivalent beam and finite strip models of the stiffened panel are shown in Figure 31. These calculations were performed using the pressure-time loading shown in Figure 26.

The numerical displacement results obtained using these models for the initial 50 ms are illustrated in Figure 32 together with the experimental data and the DRES ADINA calculations. The finite strip calculations were then carried out to 440 ms (see Figure 33). The panel center is predicted to exhibit greater elastic vibrations and then a buckling instability at 280 ms, referred to as an 'oil-canning' phenomena, after which the plating vibrates in a bowed-up shape relative to the deformed beams. If the buckling instability is ignored (since it did not occur), the finite strip results are in good agreement with the measured data. The effects of damping on the elastic vibrations and the occurrence of the 'oil-canning' phenomena warrant further investigation. There are obvious advantages to using the simplified methods in that computational times are between 10 to 20 minutes compared to 30 hours for the ADINA calculations, so that the predictions are obtained at substantially reduced cost.

8. CONCLUDING REMARKS

Event MINOR SCALE provided a unique opportunity to measure the response of the stiffened panel structure for a long duration pressure loading typical of a nuclear weapon explosion. The 345 kPa peak overpressure level with about 200 ms positive duration exposed the panel to a loading sufficient to cause permanent deformation.

The permanent deformations of 25 mm for the panel and 15 mm for the beam were less than the pretest predictions. Acceleration levels between 1000 – 2000 G were about what were expected. Strain levels up to 3500 $\mu\varepsilon$ were measured on the upper surface due to combined tensile bending and membrane effects. Higher strains are likely (but were not measured) closer to the boundary as a result of the plastic hinging effects.

The discrepancy between the experimental data and the pretest predictions was directly related to the loading function used in the analyses. By using the actual measured pressure loading the dynamic response analysis showed excellent agreement between the numerical results and the measured acceleration and displacement data. This illustrates that in order to examine the details of structural response, it is necessary to use the actual pressure loading. Nevertheless, for the purpose of preliminary design analysis and planning an experiment, the HULL code prediction was found to be quite adequate in giving the general features of the pressure loading.

The success of the panel experiment at event MINOR SCALE substantiated the trials procedures, data recording and processing techniques that were used. The correlation of results verified the suitability of the finite element code ADINA for detailed analysis of structural response, whereas the simplified computational methods based on the finite element equivalent beam and finite strip techniques have been shown to be suitable for preliminary design analysis.

The experiment fulfilled the objectives of the task by subjecting a full-scale ship's stiffened panel to a long duration air-blast loading sufficient to cause permanent plastic deformation, and by establishing the resulting pattern and mechanism of failure. The good correlation of the experimental data and numerical results validated the computational methods for long duration type of loading function and for structures sustaining limited amount of permanent deformation. The methods can now be used with confidence in ship design for carrying-out structural response analyses and damage assessment studies.

However, for structures experiencing considerably higher plastic deformation and damage, further tests and analyses are recommended for complete validation of the computational methods.

REFERENCES

1. J.E. Slater and R. Houlston. "Dynamic Analysis of Beams and Plates Subjected to Air-Blast Loading". Presented at the 3rd Inter. Modal Analysis Conf., Orlando, January 1985.

2. R. Houlston and J.E. Slater. "Structural Response of Panels Subjected to Shock Loading". Presented at the 55th Shock and Vibration Symposium, Dayton, October 1984. Published in the 55th Shock and Vibration Bulletin, Part 2, 149 – 163, June 1985.

3. R. Houlston, J.E. Slater, N. Pegg and C. DesRochers. "On Analysis of Structural Response of Ship Panels Subjected to Air Blast Loading". Presented at the 5th ADINA Conf., M.I.T., June 1985. Published in the Computer and Structures, Vol. 21, No. 1/2, pp. 273 – 289, 1985.

4. R. Houlston and J.E. Slater. "A Summary of Experimental Results on Square Plates and Stiffened Panels Subjected to Air Blast Loading". Presented at the 57th Shock and Vibration Symposium, New Orleans, Louisiana, USA, October 1986. Published in the 57th Shock and Vibration Bulletin, Part 2, 55 – 67, January 1987.

5. R. Houlston and C.G. DesRochers. "Nonlinear Structural Response of Ship Panels Subjected to Air Blast Loading". Presented at 6th ADINA Conference, MIT, June 1987. Published in Computers and Structures, Vol. 26, No. 1/2, pp. 1 – 15, 1987.

6. R. Houlston, D. Ritzel, J.E. Slater, G. Rude and R.T. Schmitke. "Air-Blast Experiments on Square Plates". Suffield Memorandum No. 1143, January 1986. (U).

7. R. Houlston, D. Ritzel, J.E. Slater and G. Rude. "Air-Blast Experiments on DRES Stiffened Panels 1 – 3". Suffield Memorandum No. No. 1214, in review. (U).

REFERENCES (Cont'd)

8. J.E. Slater. "Ship Stiffened Panel Structure". DNA MINOR SCALE Symposium, February 1986.

9. D.V. Ritzel. "Measurements from DRES Blast Gauge Stations: West Radial". DNA MINOR SCALE Symposium, February 1986.

10. D.V. Ritzel. "The DRES Blast-Gauge Station". Presented at the Ninth International Symposium on the Military Applications of Blast Simulation (MABS 9), England, September 1985.

11. W.E. Baker, J.J. Kulesz, P.S. Westine, P.A. Cox and J.S. Wilbeck. "A Manual for the Prediction of Blast and Fragment Loading on Structures". U.S. Dept. of Energy Report, DOE/TIC-11268, November 1980.

12. W.E. Baker, P.A. Cox, P.S. Westine and J.J. Kulesz. **Explosion Hazards and Evaluation.** Fundamental Studies in Engineering 5, Elsevier Scientific Publishing Company, 1983.

13. W.E. Baker. **Explosions in Air.** University of Texas Press and Southwest Research Institute, 1973.

14. S. Glasstone and P.S. Dolan. **The Effects of Nuclear Weapons.** Third Edition, The United States Dept. of Defence and the U.S. Dept. of Energy, 1977.

15. **Engineering Design Handbook – Explosions in Air, Part One.** Headquarters, U.S. Army Material Command, AMC Pamphlet, AMCP-706-181, 15 July 1974.

16. C.G. DesRochers and M.E. Norwood. "A Computerized Procedure for Defining Air Blast Loading on Structural Elements: User's Manual". MARTEC Ltd., Halifax, N.S., DRES Contract Report No. 28/86, March 1986.

REFERENCES (Cont'd)

17. J.M. Dewey and D.J. McMillin "Compendium of Blast Wave Properties". Final Report, University of Victoria, B.C., DRES Contract Report No. 17/87, February 1987.

18. T. Otvos. "General Two-Dimensional Compressible Flow Calculations Using SPLIT2D: User's Guide". Version 1.3, Combustion Dynamics Ltd., November 1986.

19. M.A. Fry. "The HULL Hydrodynamics Computer Code". AFWL-TR-76-183, Air Force Weapons Laboratory, September 1976.

20. S.C.M. Lau and J.J. Gottlieb. "Numerical Reconstruction of Part of an Actual Blast-Wave Flow Field to Agree with Available Experimental Data". UTIAS Technical Note No. 251, University of Toronto Institute for Aerospace Studies, Downsview, Ontario, August 1984.

21. T.R. Stagliano and L.J. Mente. "Large Deflection, Elastic-Plastic Dynamic Structural Response of Beams and Stiffened or Unstiffened Panels – A Comparison of Finite Element, Finite Difference and Model Solutions". Nonlinear Finite Element Analysis and Adina, Proc. ADWA Conference, 1979.

22. B.R. Folz. "Documentation for the Program FENTAB, Finite Element Nonlinear Transient Analysis of Beams, Version 1.0". Department of Civil Engineering, University of British Columbia, Vancouver, B.C., May 1986.

23. "Vibration and Strength Analysis Program (VAST): User's Manual". Version No. 04, MARTEC Ltd., Halifax, N.S., January 1986.

24. "ADINA – A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis". Report AE 84-1, ADINA Engineering Inc., Mass. USA, December 1984.

REFERENCES (Cont'd)

25. "Vibration and Strength Analysis Graphics Program (VAST-G): User's Manual". MARTEC Ltd., Halifax, N.S., 1986.

26. C.G. DesRochers, D.F. Fanning and M.E. Norwood. "Computer Codes for Structural Response to Air Blast: User's Manual". MARTEC Ltd., Halifax, N.S., DRES Contract Report No. 35/86, March 1986.

27. C.G. DesRochers and M.E. Norwood. "VAST/ADINA Interface Program (ADIDAT): User's Manual". MARTEC Ltd., Halifax, N.S., July 1983.

28. C.G. DesRochers and M.E. Norwood. "VAST/ADINA Graphics Interface Program (ADIPOS): Final Report". MARTEC Ltd., Halifax, N.S., October 1983.

29. C.G. DesRochers and M.E. Norwood. "Analysis of Ship Stiffened Panel Structures Subjected to Air Blast Loading: Final Report". MARTEC Ltd., Halifax, N.S., DRES Contract Report No. 27/86, March 1986.

30. Y.K. Cheung. **Finite Strip Method in Structural Analysis.** Pergamon Press, 1976.

31. R.M. Khalil, M.D. Olson and D.L. Anderson. "Large Deflection, Elastic-Plastic Dynamic Response of Air-Blast Loaded Plate Structures by the Finite Strip Method". Structural Research Series Rept. No. 33, Dept. of Civil Engineering, University of British Columbia, Vancouver, B.C., January 1987.

32. M.D. Olson and D.L. Anderson. "Modelling of Structural Response to Air Blast - Phase II". Final Report for Contract No. 01SG.97702-R-4-8568, Department of Civil Engineering, University of British Columbia, Vancouver, B.C., January 1987.

REFERENCES (Cont'd)

33. J.S. Hansen and G.R. Heppler. "Defence Research Establishment Suffield Dynamic Code (DRESDYN) Users' Manual". UTIAS, Toronto, DRES Contract Report No. 30/85, September 1984.

34. J.S. Hansen and G.R. Heppler. "Development of a Finite Element Capability for the Analysis of Structural Systems Subjected to a Nuclear Blast Environment - Phase II Beams and Composite Material Shells". Final Report Submitted to Defence Research Establishment Suffield under Contract No. 01SG.97702-R-4-8710, UTIAS, Toronto, November 1986.

35. C.G. DesRochers and M.E. Norwood. "Finite Element Analysis of Stiffened Panels Subjected to Air Blast Loading". MARTEC Ltd., Halifax, N.S., DRES Contract Report No. 55/85, April 1985.

36. R. Houlston and J.E. Slater. "SPADE - An Interactive Computer Program for Signal Processing And Data Enhancement of Air-Blast Structural Response Measurements (U)". Suffield Memorandum No. 1123, March 1986. UNCLASSIFIED.

37. C.G. DesRochers and M.E. Norwood. "Finite Element Analysis of Stiffened Panel Structure Subjected to Three Air Blast Loadings". MARTEC Ltd., Halifax, N.S., DRES Contract Report No. 26/86, March 1986.

Table I

SUMMARY OF DRES HEIGHT OF BURST (HOB) TEST RESULTS FOR STIFFENED PANEL NO. 1

TRIAL NUMBER	CHARGE MASS (kg)	STAND-OFF (m)	PEAK PRESSURE (kPa)	DURATION (ms)	IMPULSE (kPa-ms)	ACCELERATION* (G)	STRAIN** (με)	REMARKS
311	3.6	21.3	17	9.3	55	+	+	ELASTIC
312	29	15.2	83	13.3	300	370	1300	ELASTIC
313	94	12.8	240	10.0	710	880	3000	JUST BELOW YIELD
314	94	10.1	450	8.2	980	1650	4000	JUST ABOVE YIELD
315	2 × 94[e] at 2.4 m SPACING	7.3	6375	3.2	6340	++	6200	SEVERE PLASTIC DEFORMATION (100 mm)

* Average Peak Value for Accelerometers Located at Panel Centre

** Average Peak Value for Strain Gauges Located at Panel Edges

\+ Negligible

++ Accelerometers Not Mounted

e Equivalent in Peak Pressure to a Single Charge Mass of 454 kg

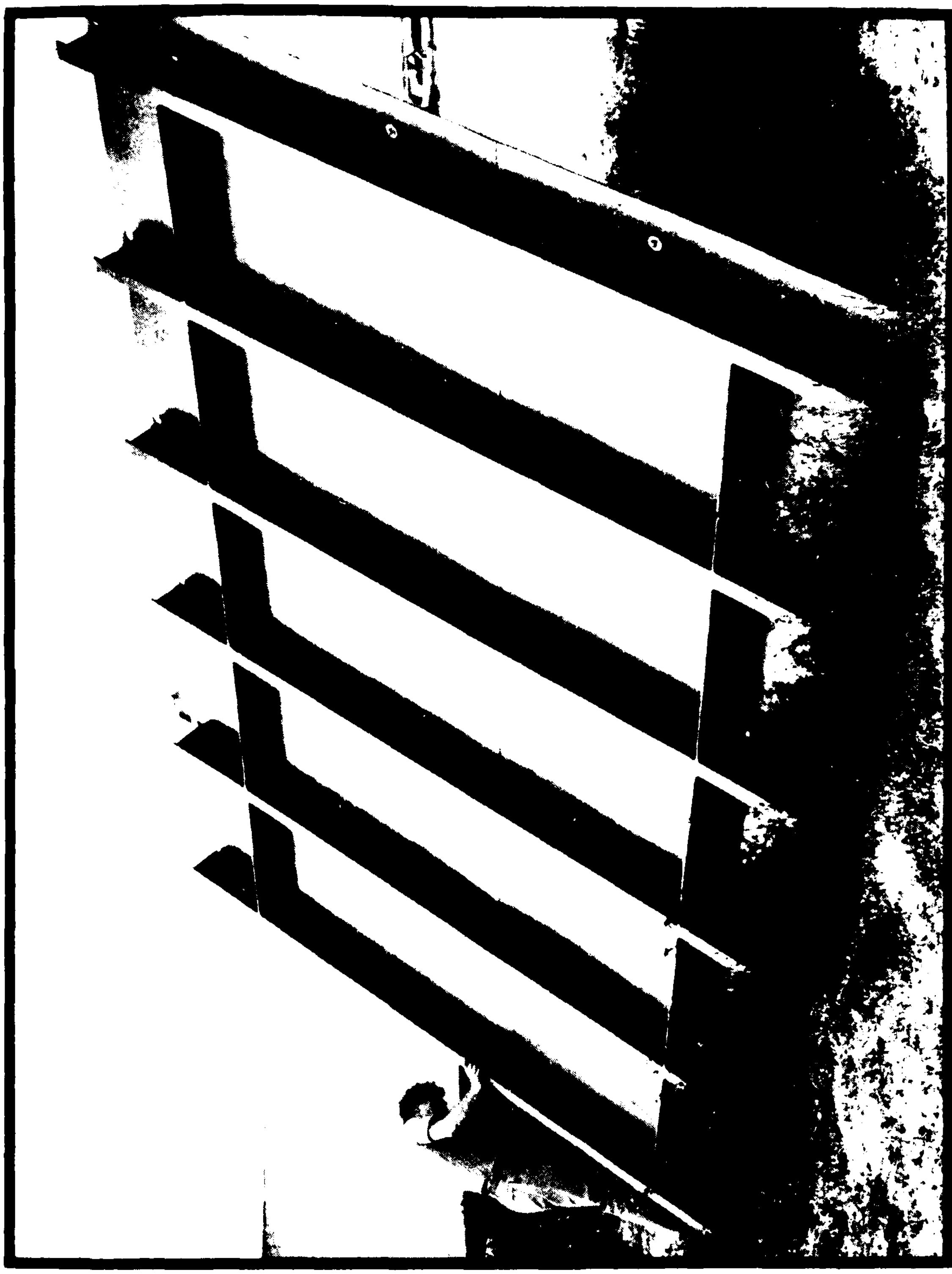


Figure 1
PHOTOGRAPH OF STIFFENED PANEL FOR DRES TESTS

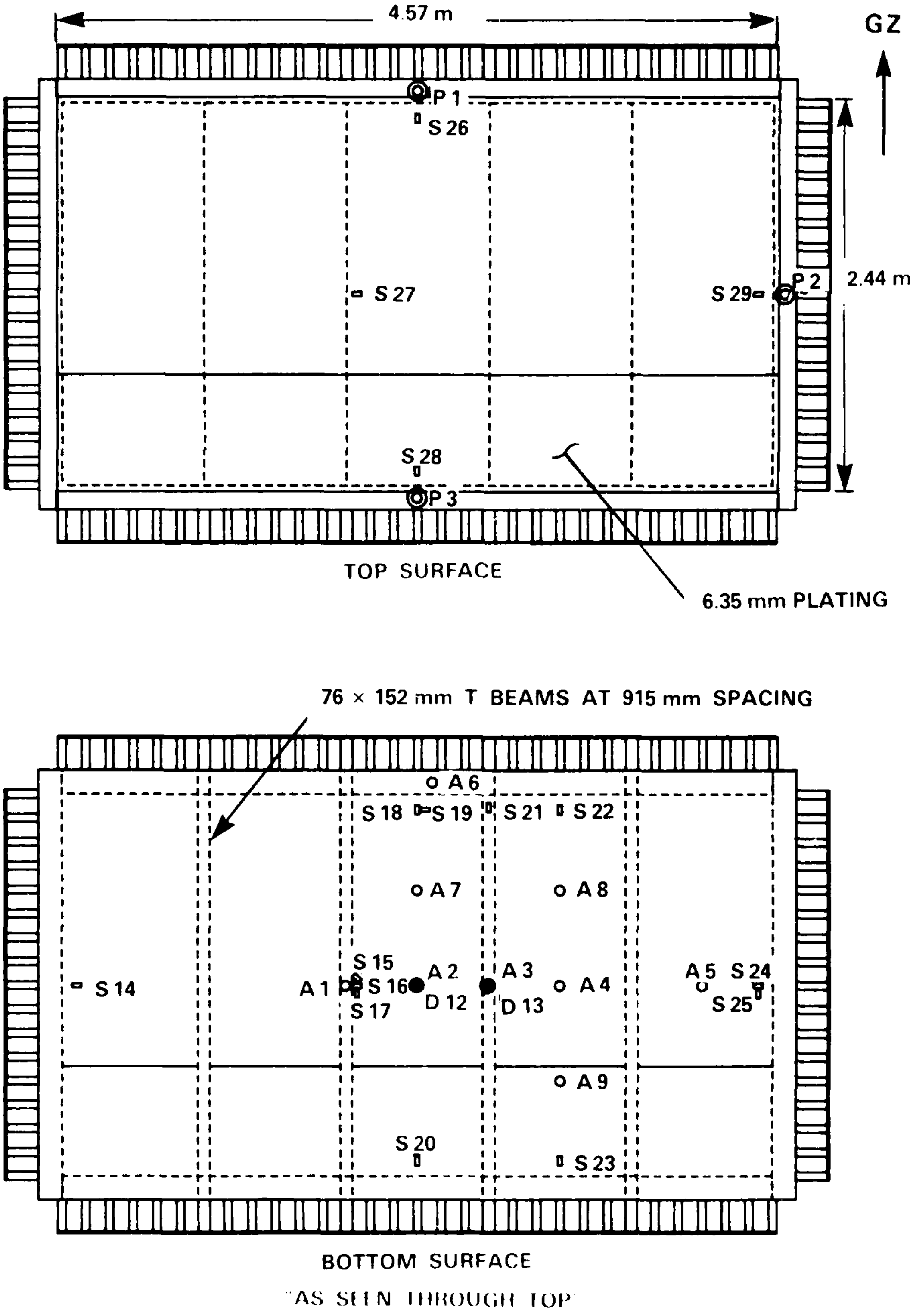
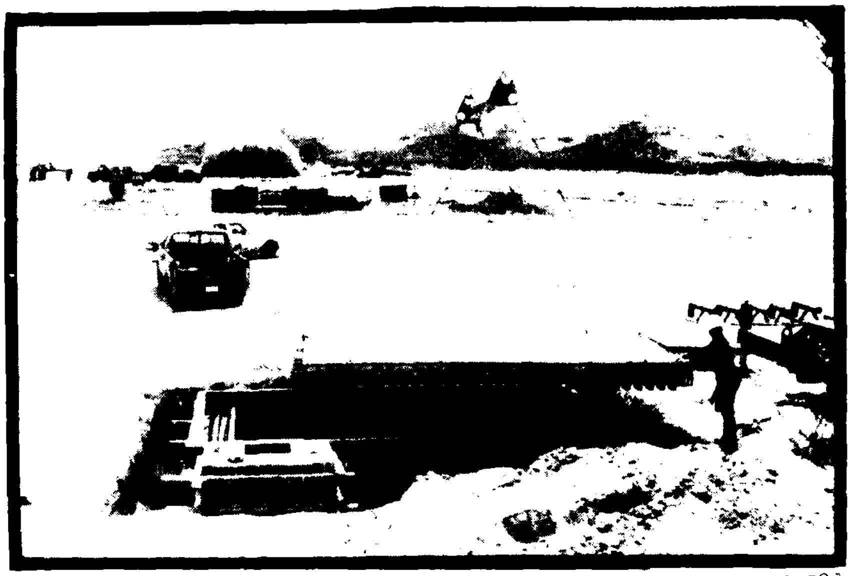


Figure 2

TRANSDUCER LOCATIONS ON STIFFENED PANEL FOR MINOR SCALE TRIAL (P = PRESSURE, A = ACCELERATION, D = DISPLACEMENT, S = STRAIN)



85 292.

Figure 3a

STIFFENED PANEL STRUCTURE BEING INSTALLED ON REINFORCED CONCRETE FOUNDATION FOR THE MINOR SCALE TEST

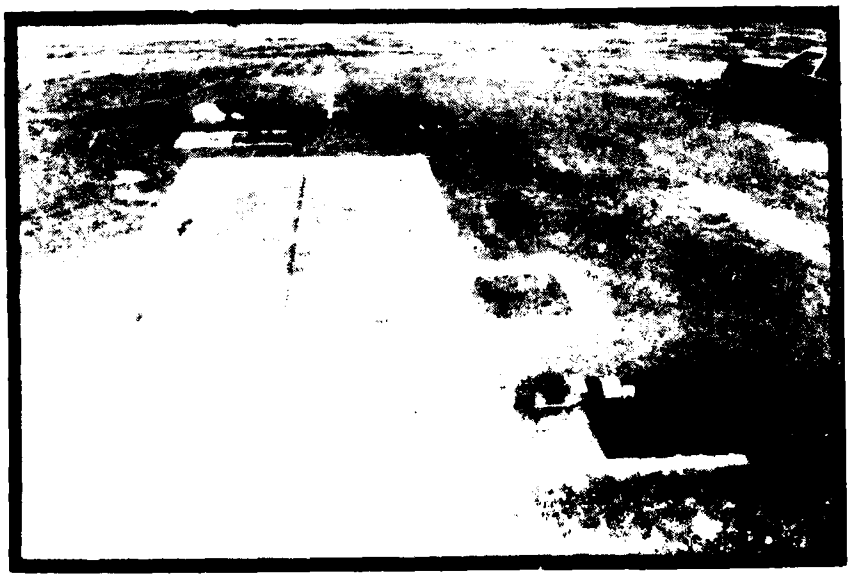
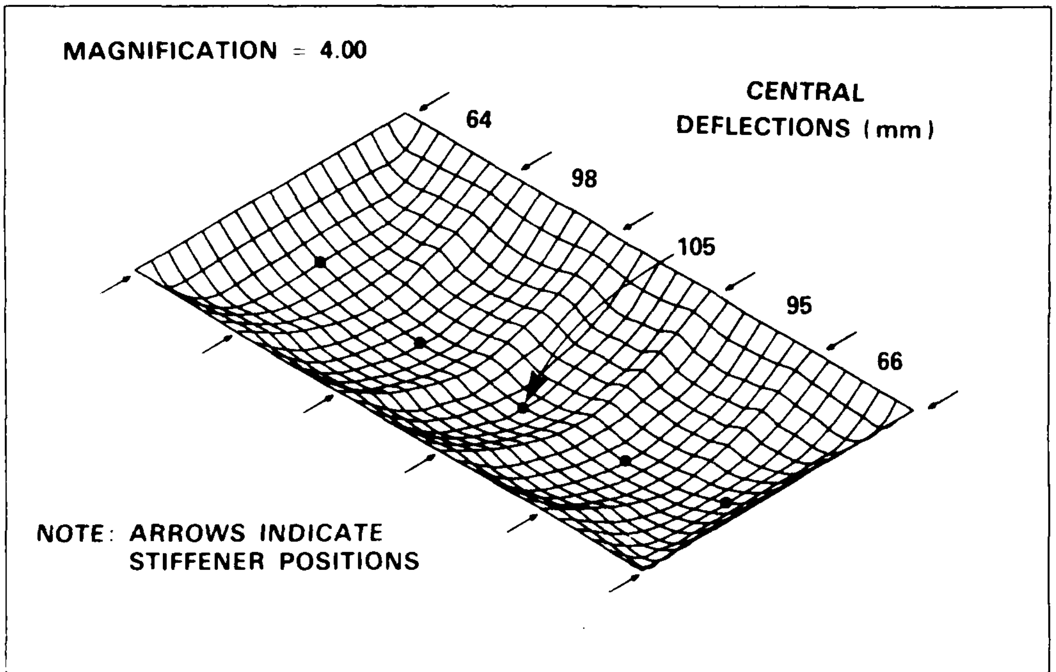


Figure 3b

PANEL AS INSTALLED FLUSH WITH THE GROUND WITH DRES BLAST-GAUGE STATIONS AT EITHER END OF THE PANEL



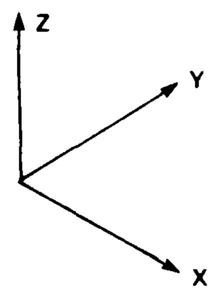


Figure 4

PANEL DEFORMATION AFTER FINAL SHOT
OF DRES HOB TESTS
(Damage Exaggerated by Expanding the Vertical Scale
by a Factor of 4)

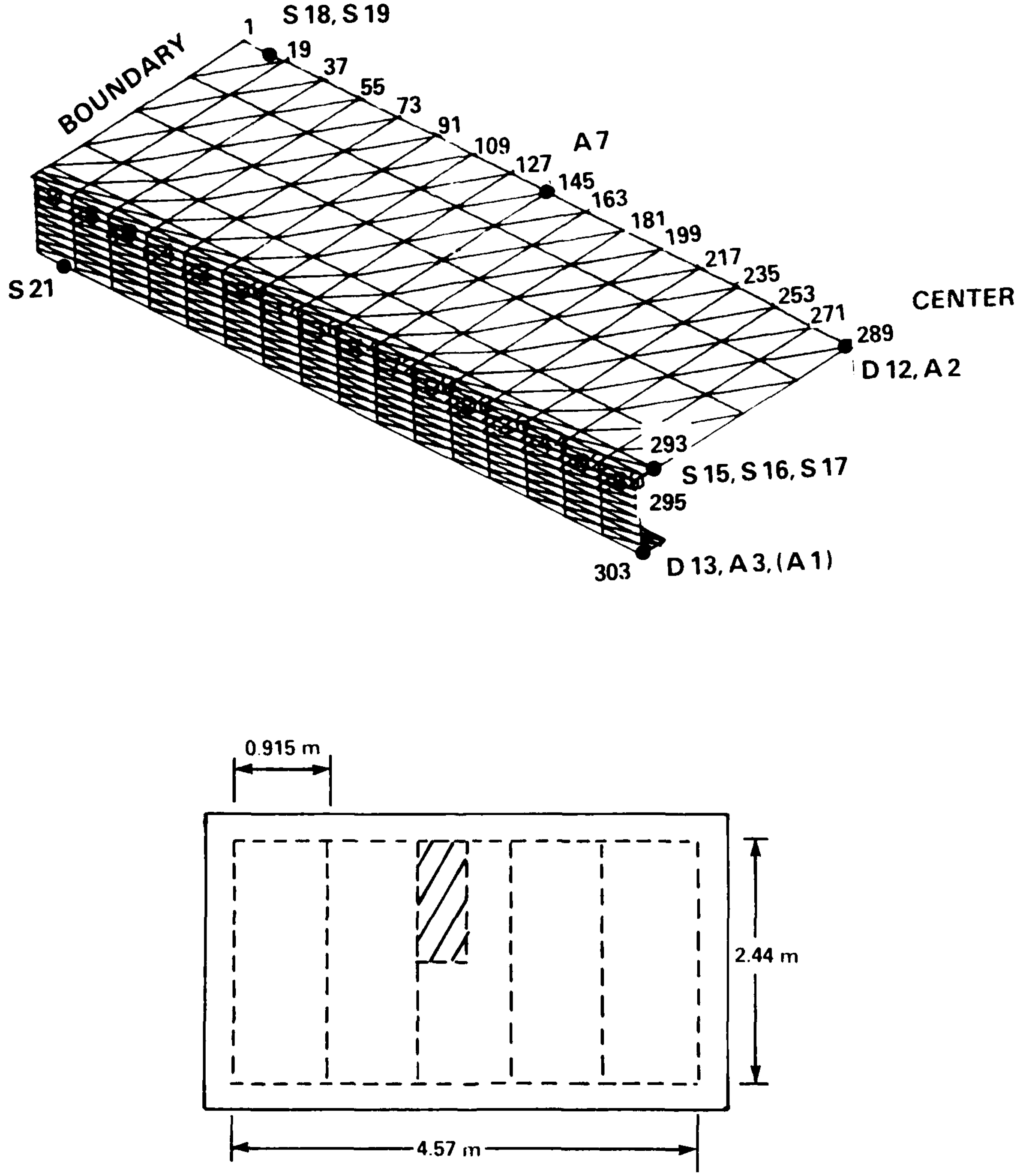


Figure 5

FINITE ELEMENT MODEL OF THE PLATE/BEAM STRUCTURE FOR A SEGMENT OF THE STIFFENED PANEL

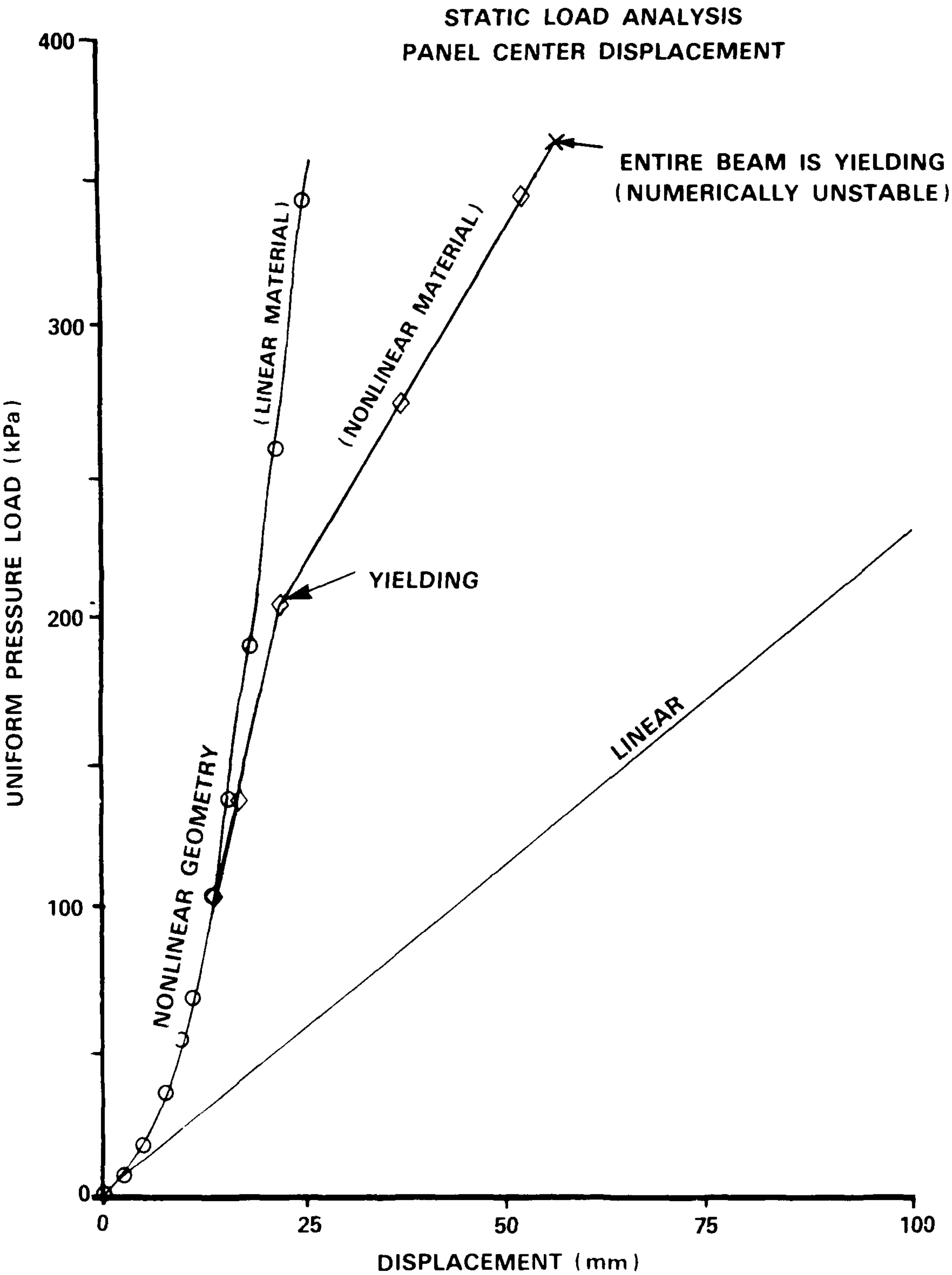


Figure 6

ADINA RESULTS OF DISPLACEMENT VERSUS STATIC LOAD FOR STIFFENED PANEL

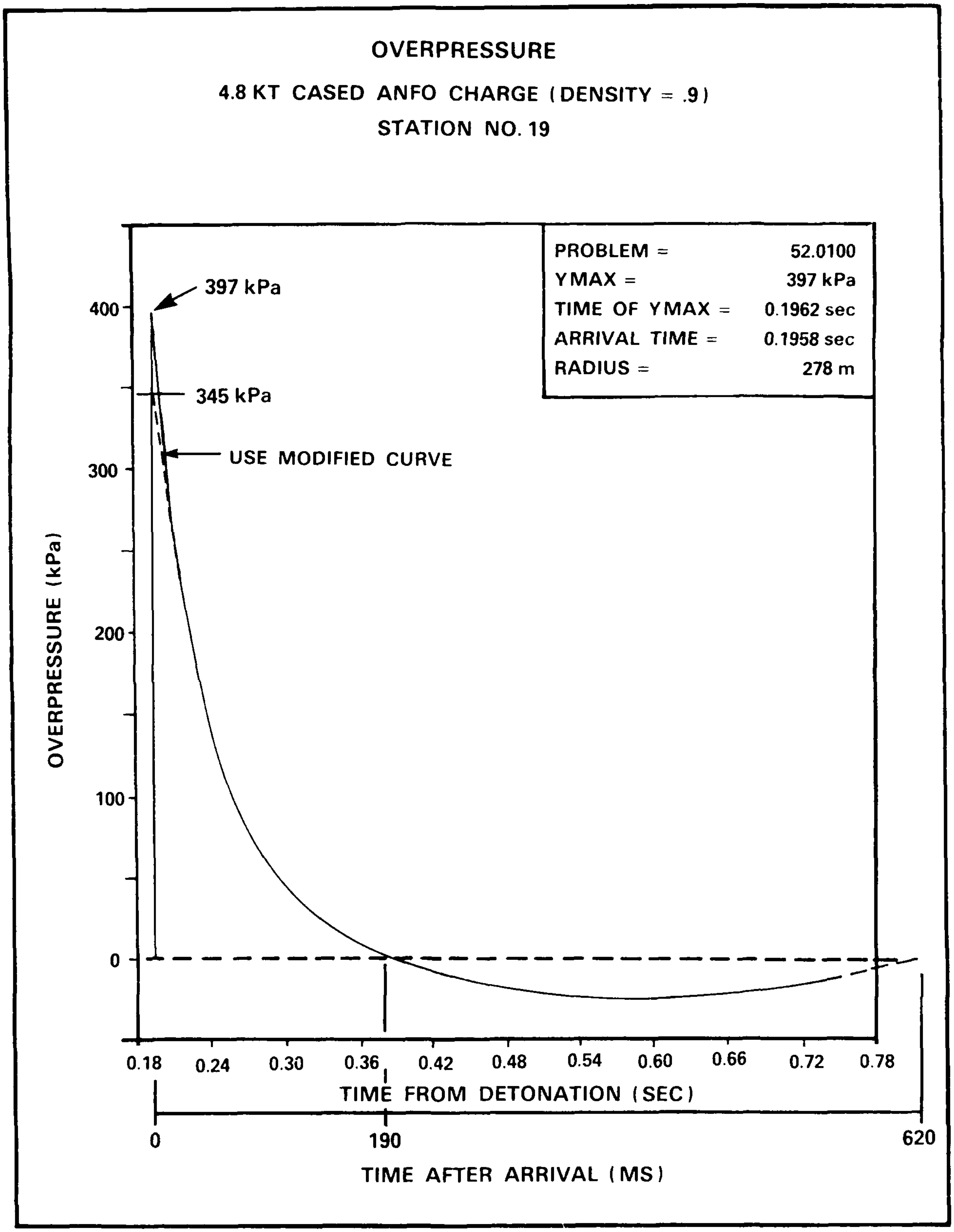
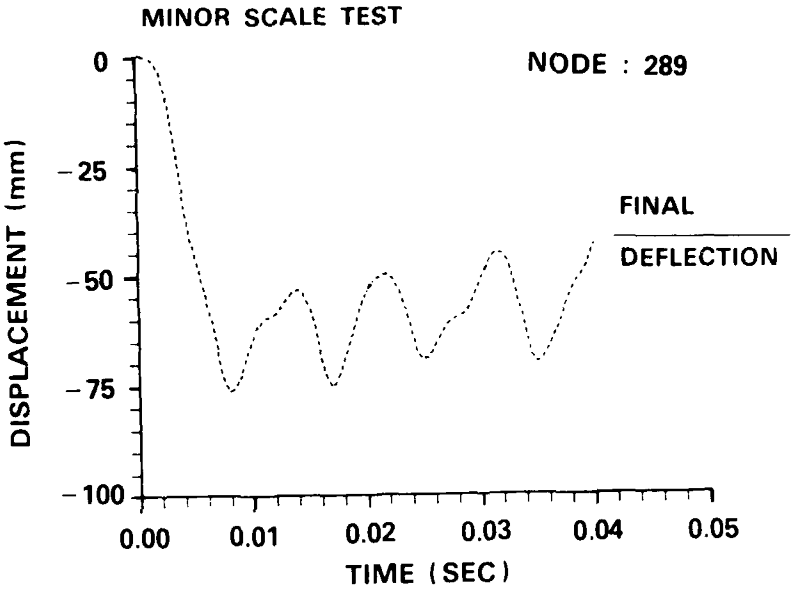
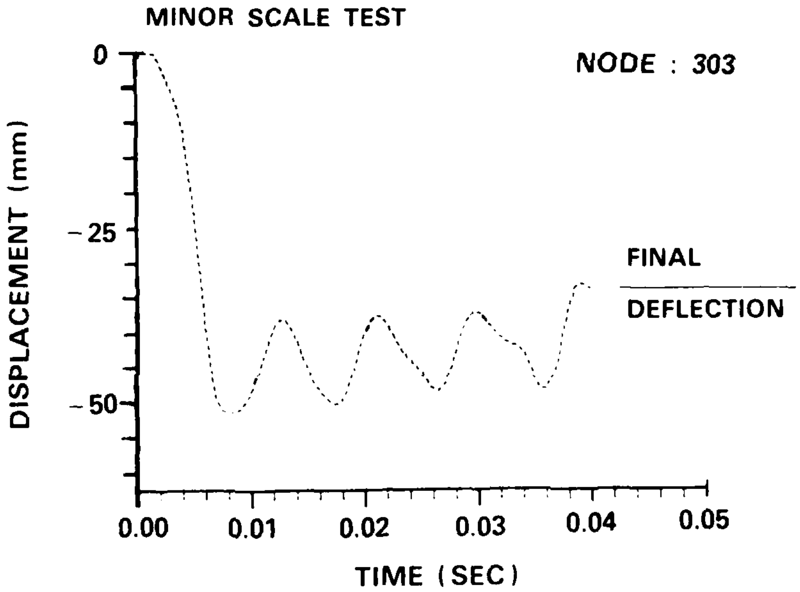


Figure 7

PREDICTED PRESSURE-TIME HISTORY LOADING FOR EVENT MINOR SCALE AT STATION 19 NEAR SITE OF STIFFENED PANEL STRUCTURE



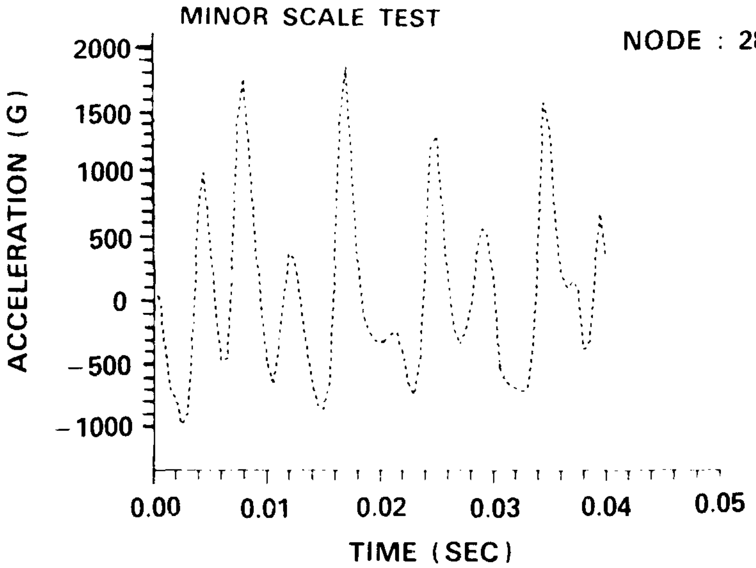
(a) CENTER OF PANEL (TRANSDUCER D 12);



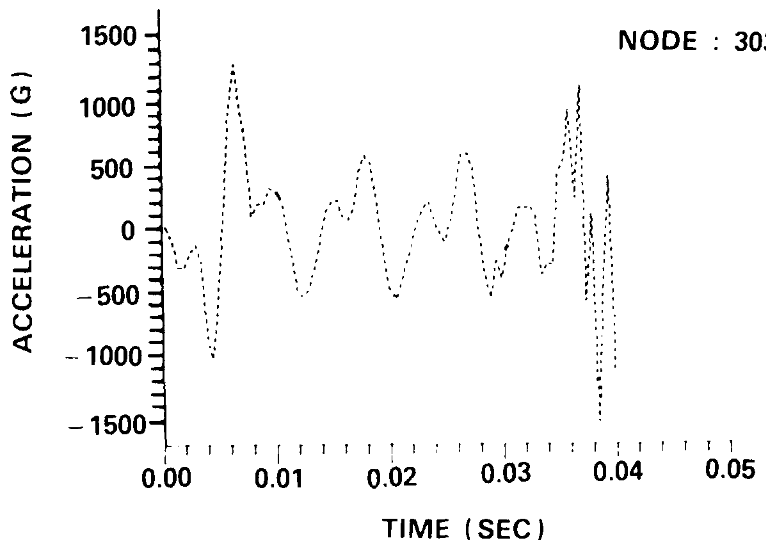
(b) MIDSPAN OF BEAM STIFFENER (TRANSDUCER D 13)

Figure 8

PRELIMINARY PREDICTIONS OF DISPLACEMENT-TIME HISTORY



(a) CENTER OF PANEL (ACCELEROMETER A2)



(b) MIDSPAN OF BEAM STIFFENER (ACCELEROMETER A3)

Figure 9

PRELIMINARY PREDICTIONS OF ACCELERATION-TIME HISTORY

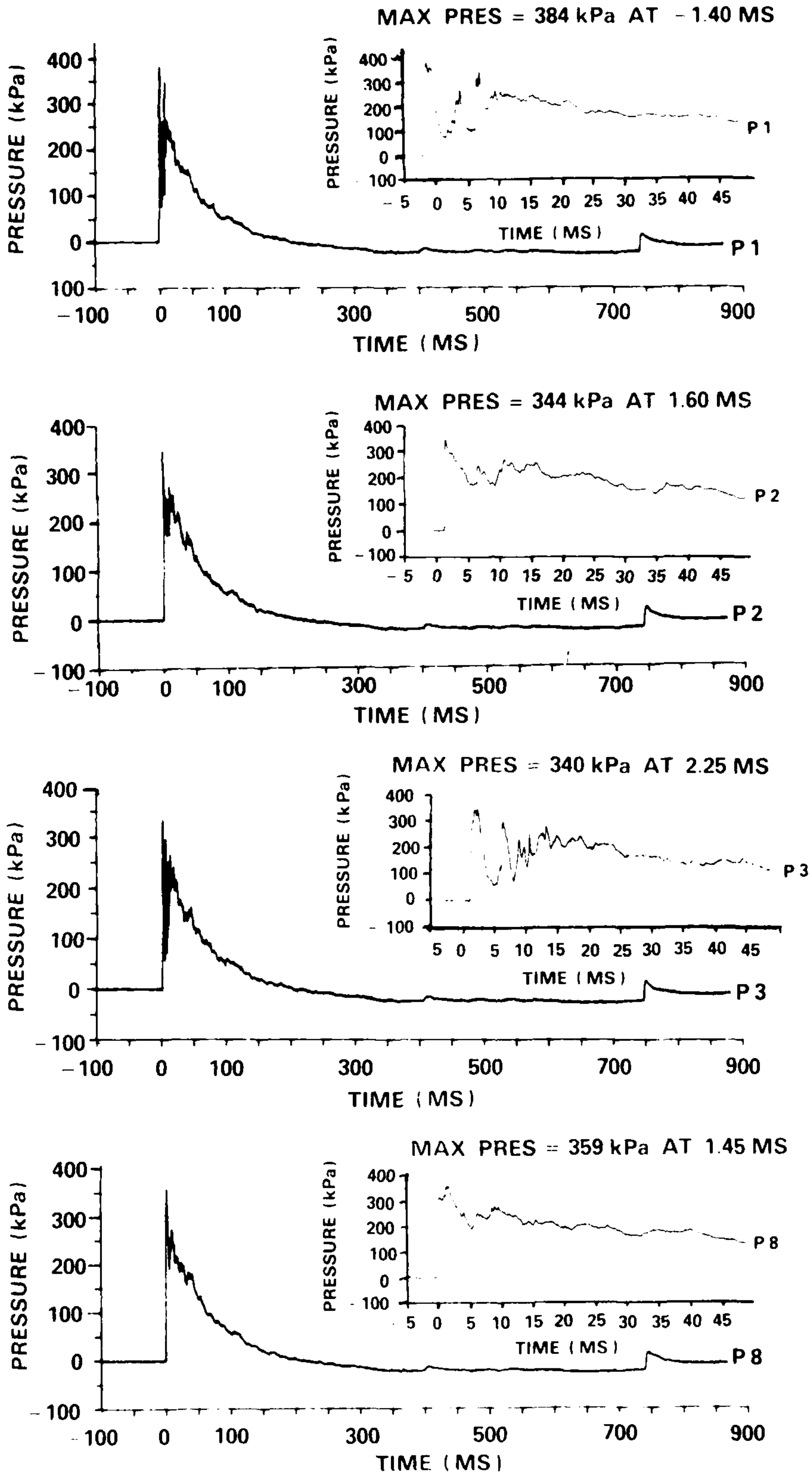


Figure 10

MEASURED SIDE-ON PRESSURE-TIME HISTORIES ON STIFFENED PANEL SURFACE (TRANSDUCERS P1 – P3) AND BLAST GAUGE STATION (TRANSDUCER P8)

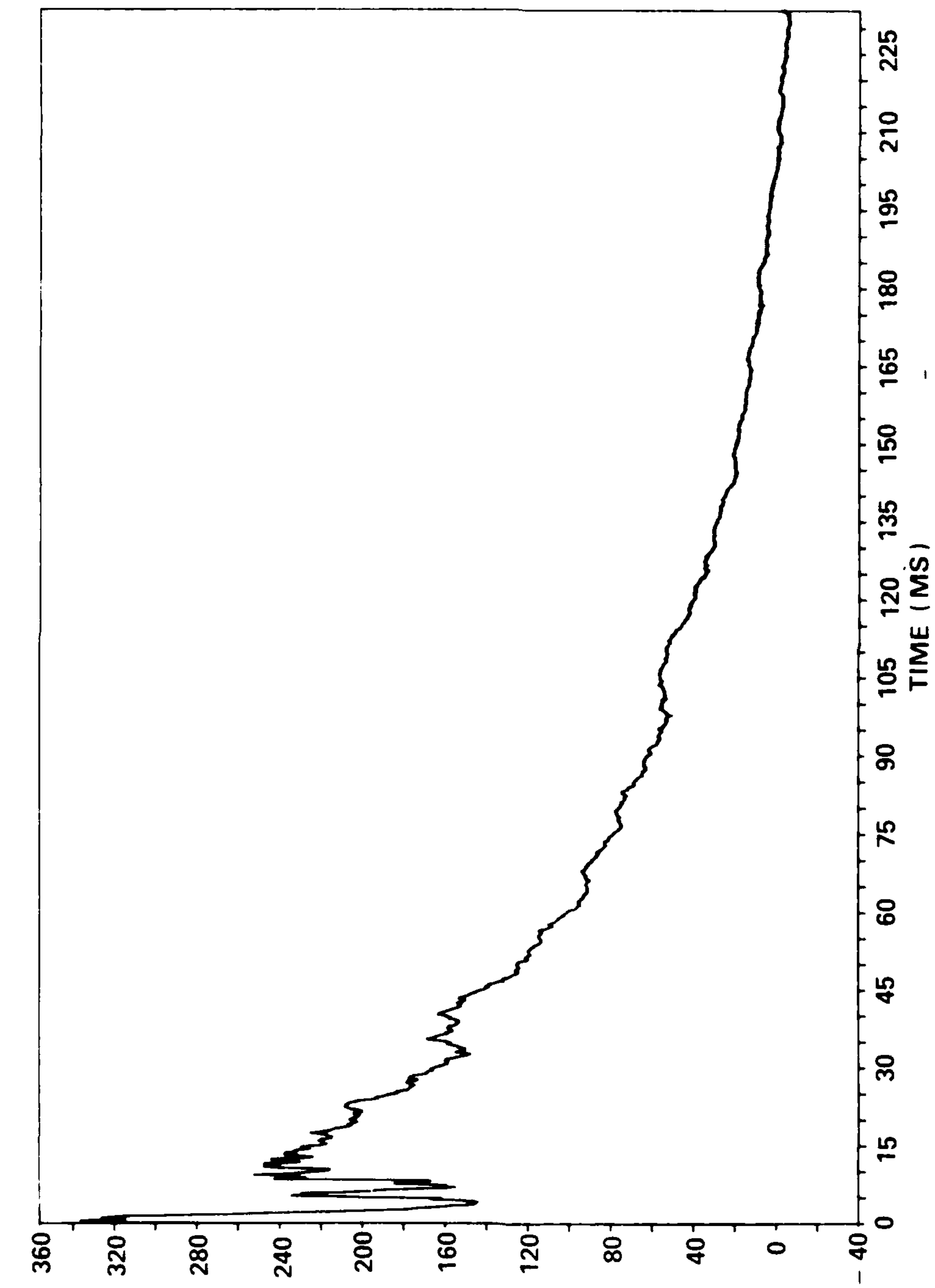
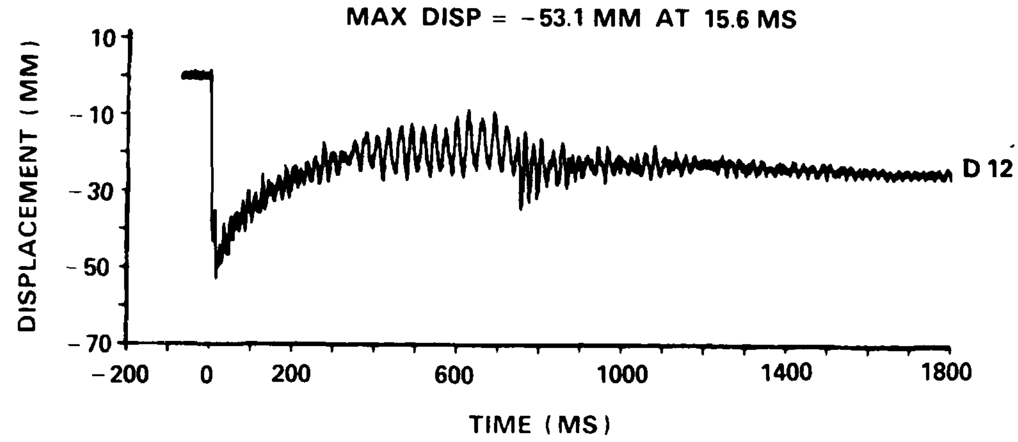
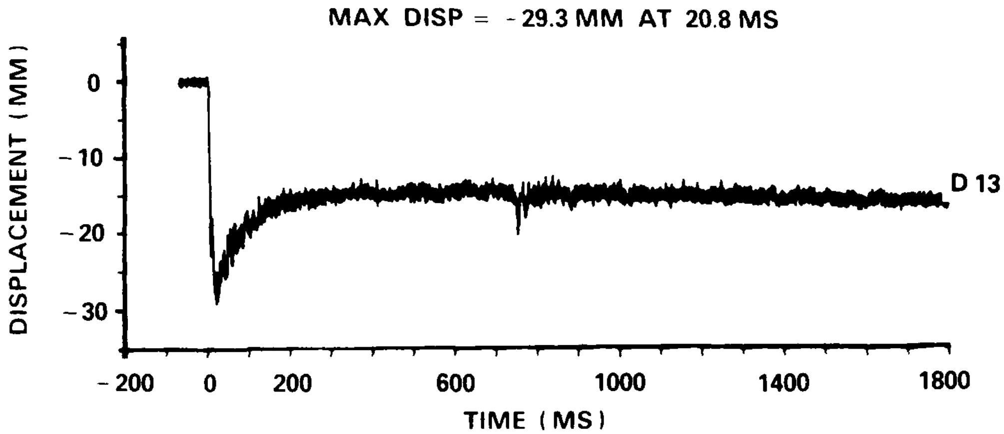


Figure 11

AVERAGED PRESSURE LOADING FROM DATA GIVEN IN FIG. 10 FOR FINITE ELEMENT ANALYSIS





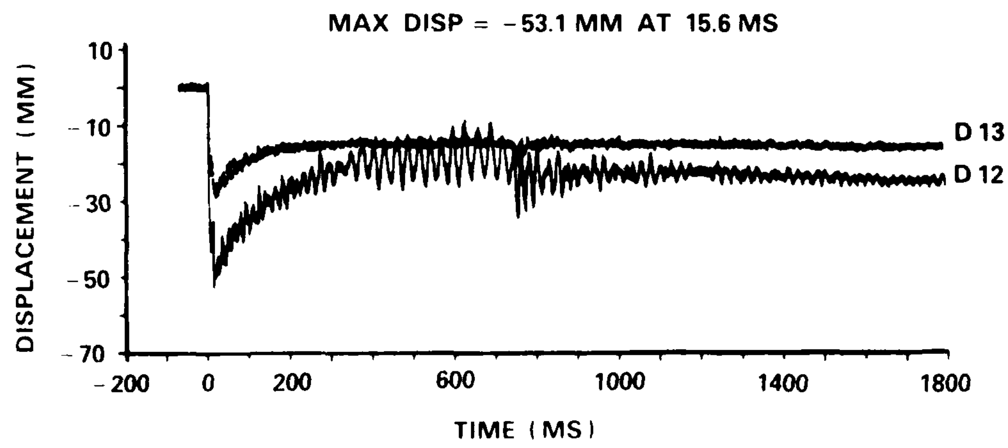


Figure 12

MEASURED DISPLACEMENT-TIME HISTORIES AT PANEL CENTER (D12) AND BEAM MIDSPAN (D13) a)

Figure 13a

POST-SHOT PHOTOGRAPH OF STIFFENED PANEL STRUCTURE AFTER MINOR SCALE

b)

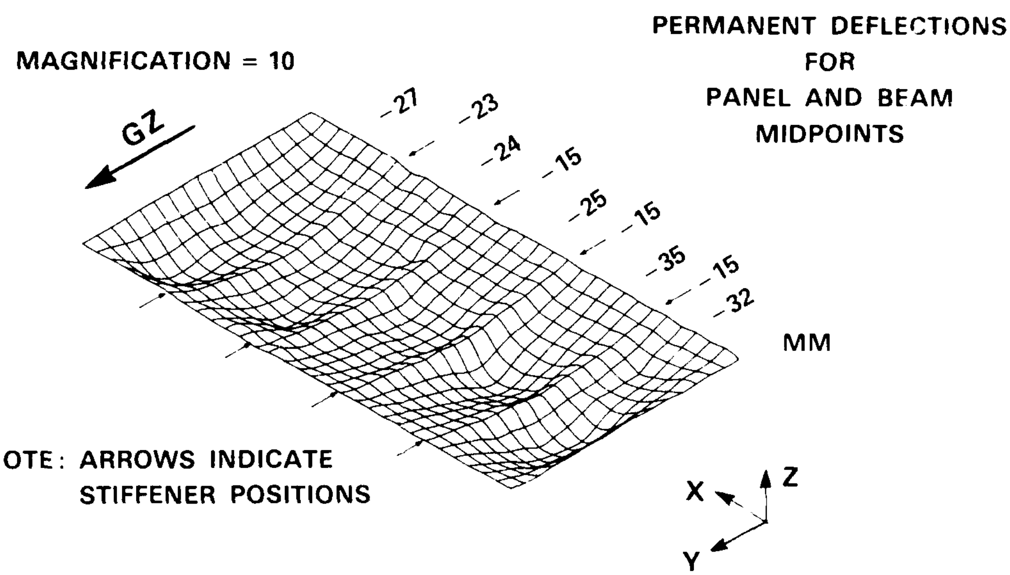


Figure 13b

FINAL DEFORMATION OF PANEL SURFACE
(Damage Exaggerated by Expanding the Vertical Scale by 10)

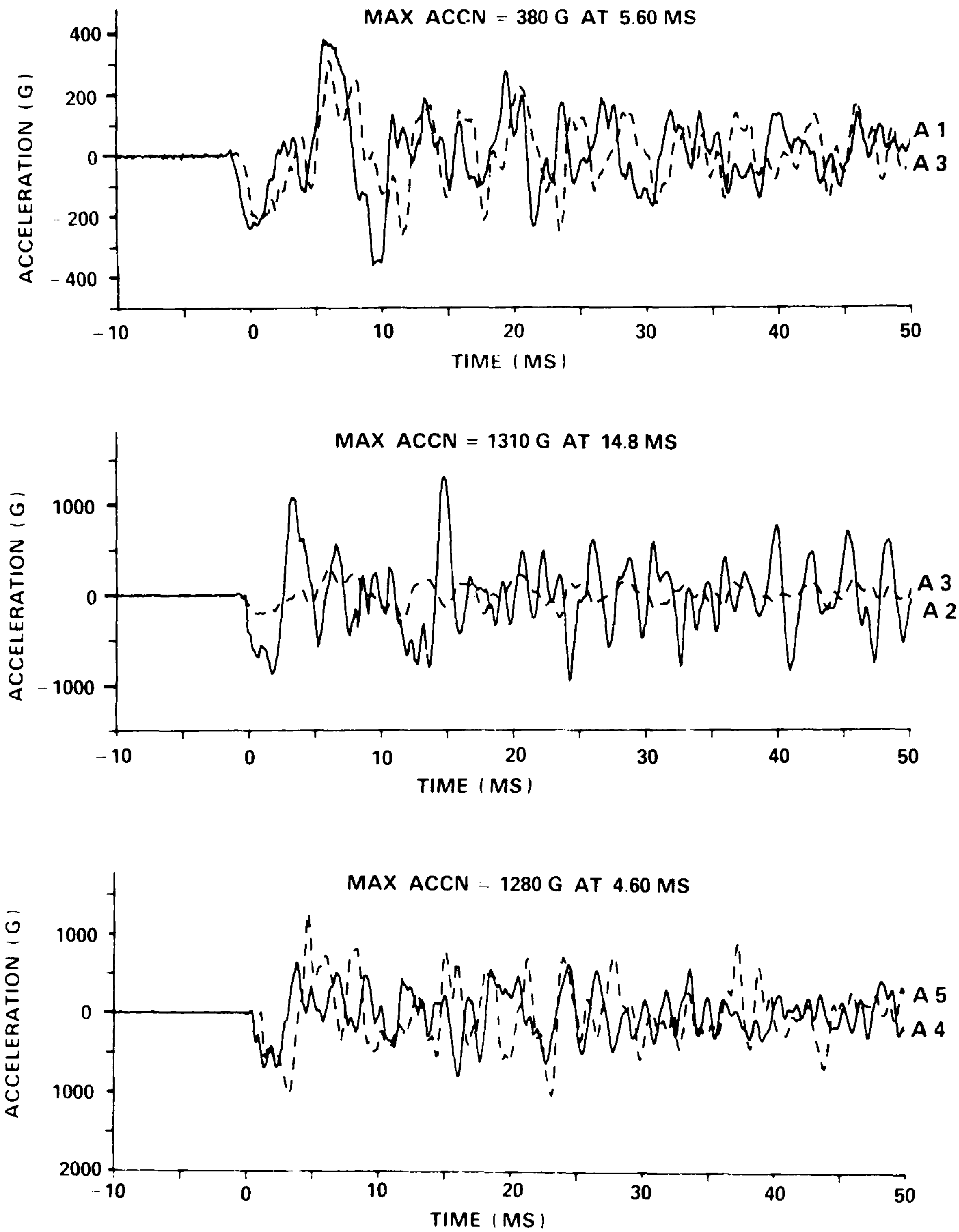


Figure 14

MEASURED ACCELERATION TIME HISTORIES ON STIFFENED PANEL

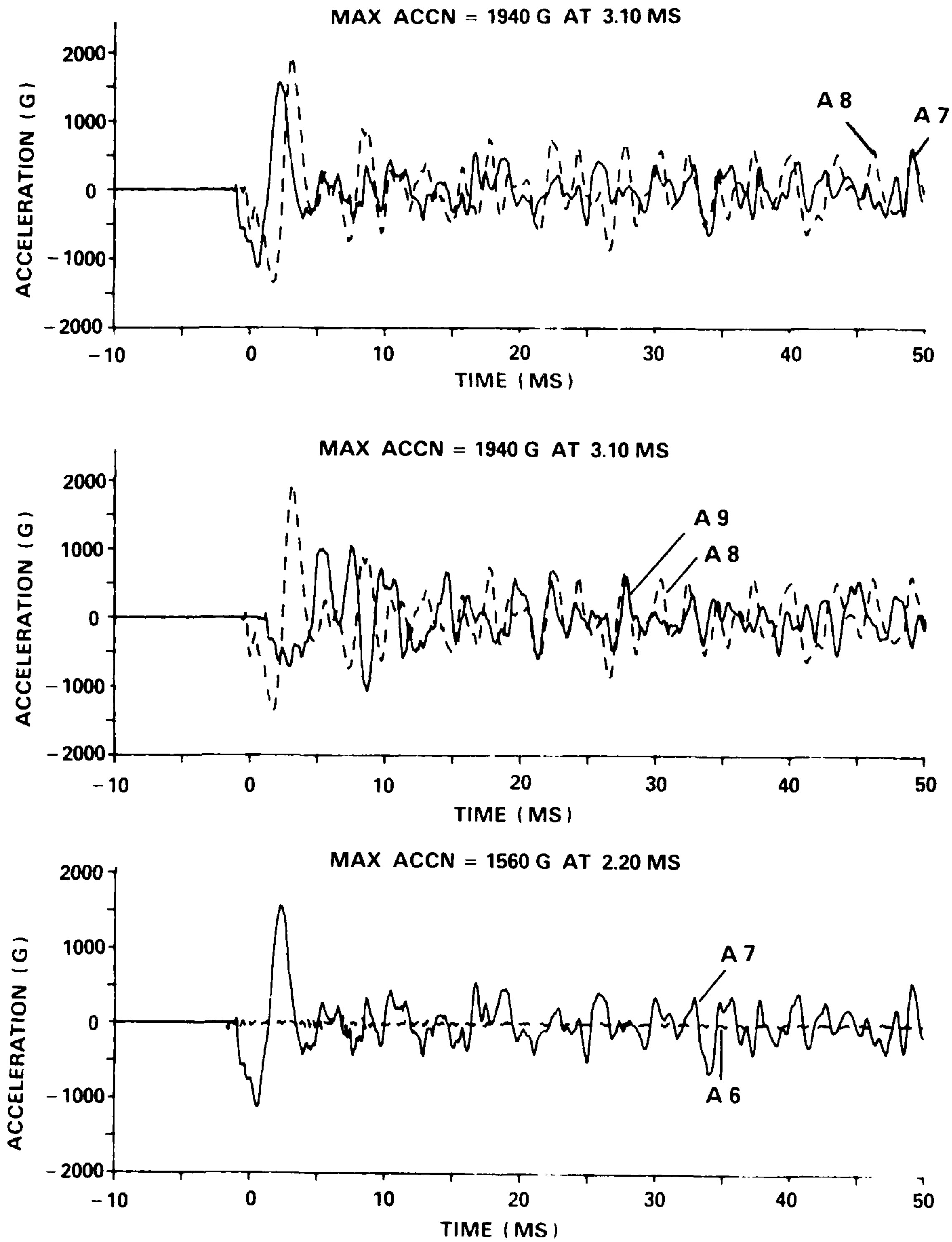
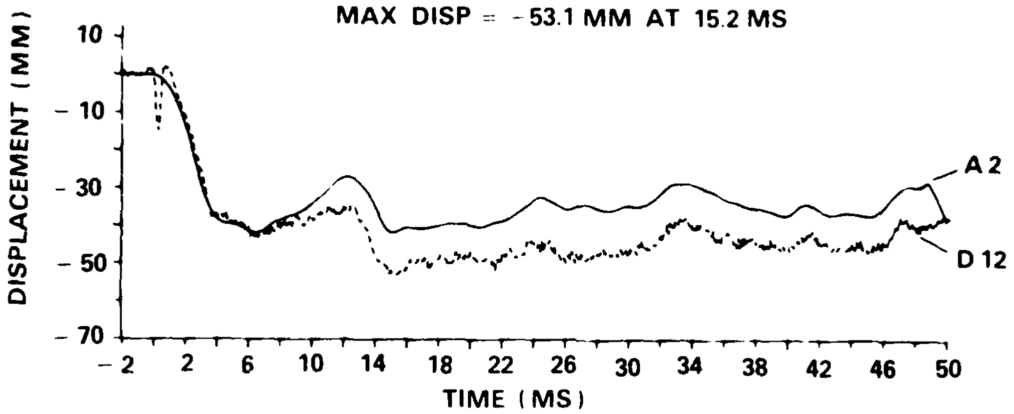
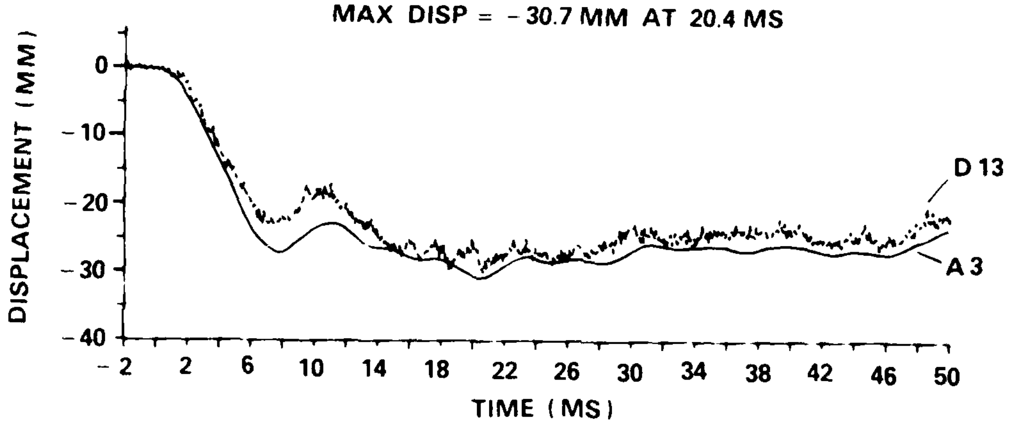


Figure 15

MEASURED ACCELERATION-TIME HISTORIES ON STIFFENED PANEL





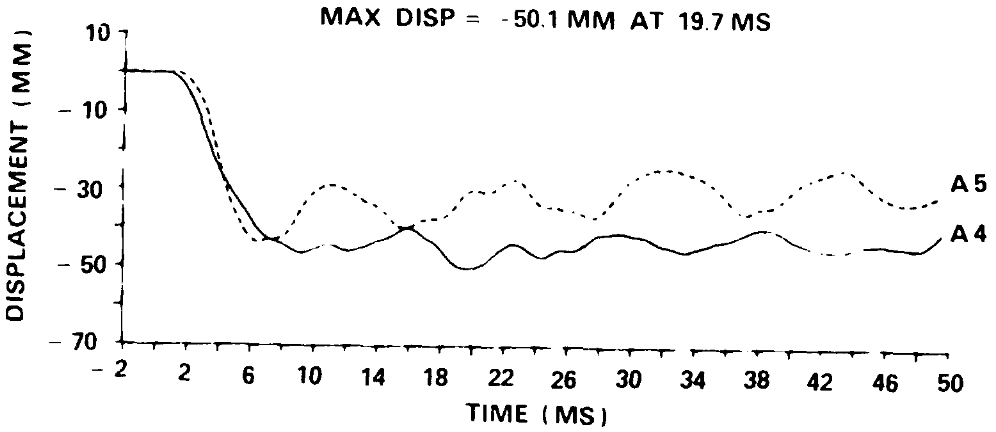


Figure 16

MEASURED DISPLACEMENT-TIME HISTORIES FROM TRANSDUCERS D12 AND D13, AND DOUBLE INTEGRATION OF ACCELEROMETER SIGNALS A2 – A5

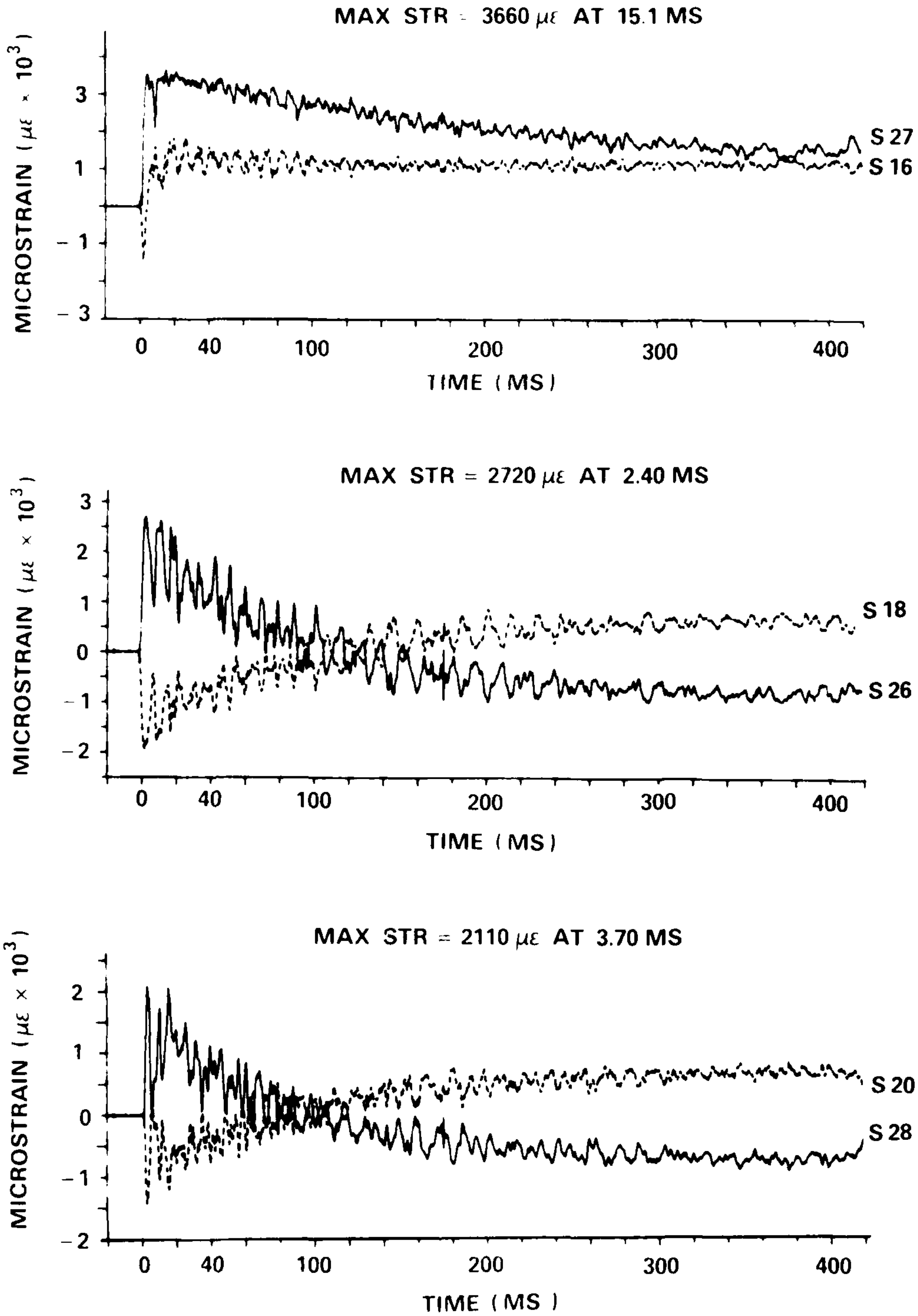


Figure 17

MEASURED STRAIN-TIME HISTORIES FROM STRAIN GAUGES ON TOP AND BOTTOM SURFACES OF PANEL

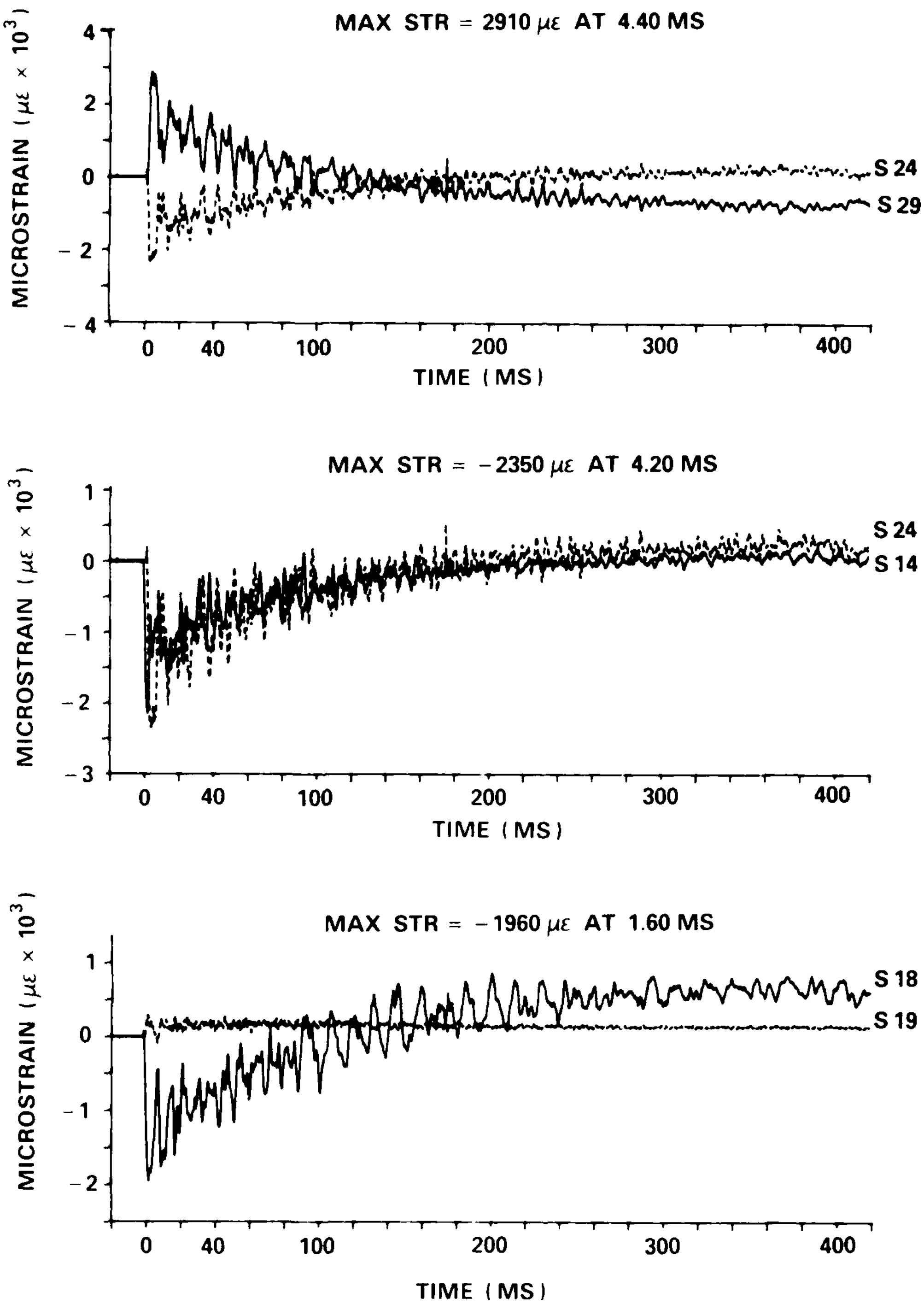


Figure 18

MEASURED STRAIN-TIME HISTORIES FROM STRAIN GAUGES AT VARIOUS LOCATIONS ON THE PANEL

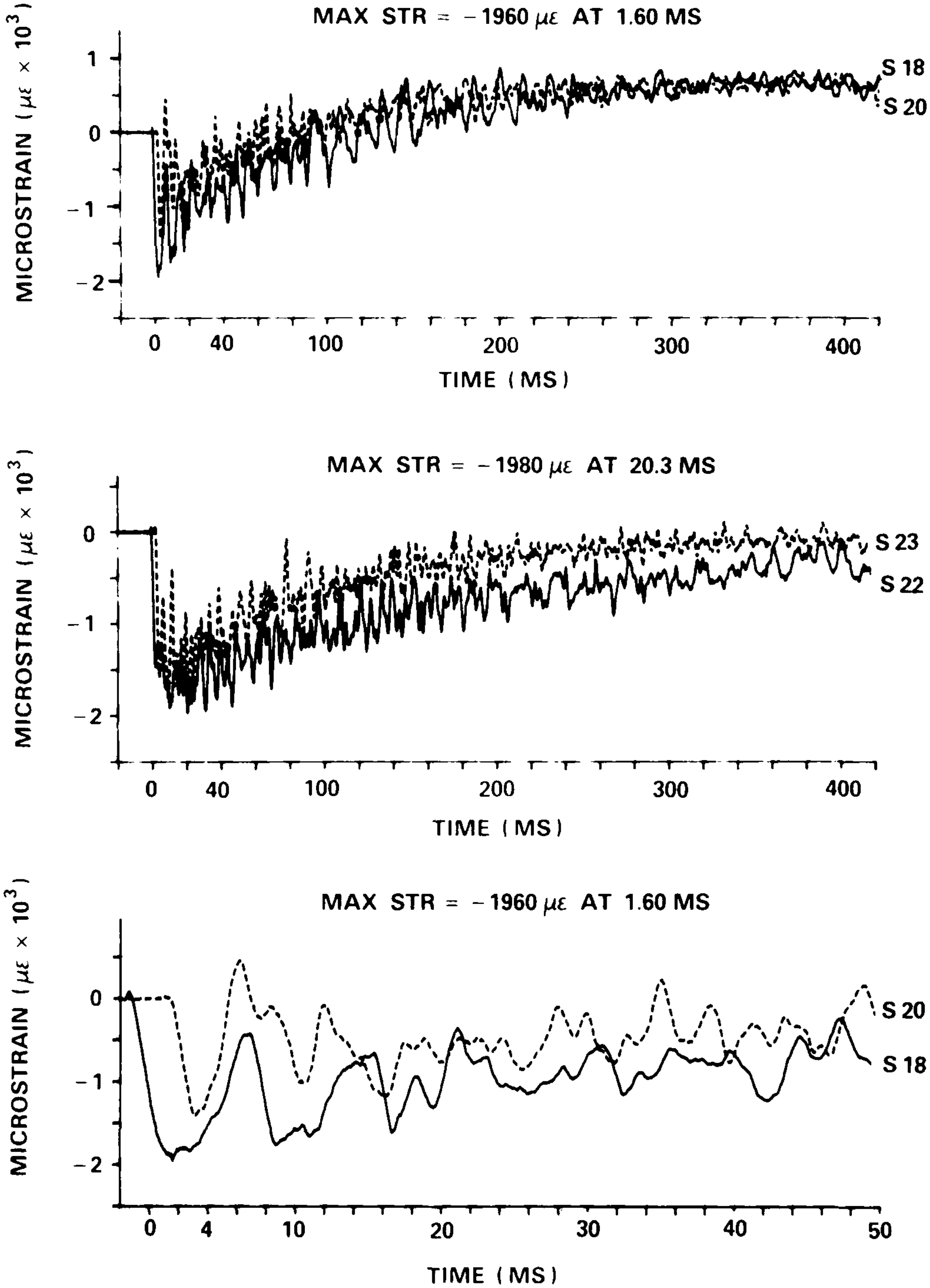
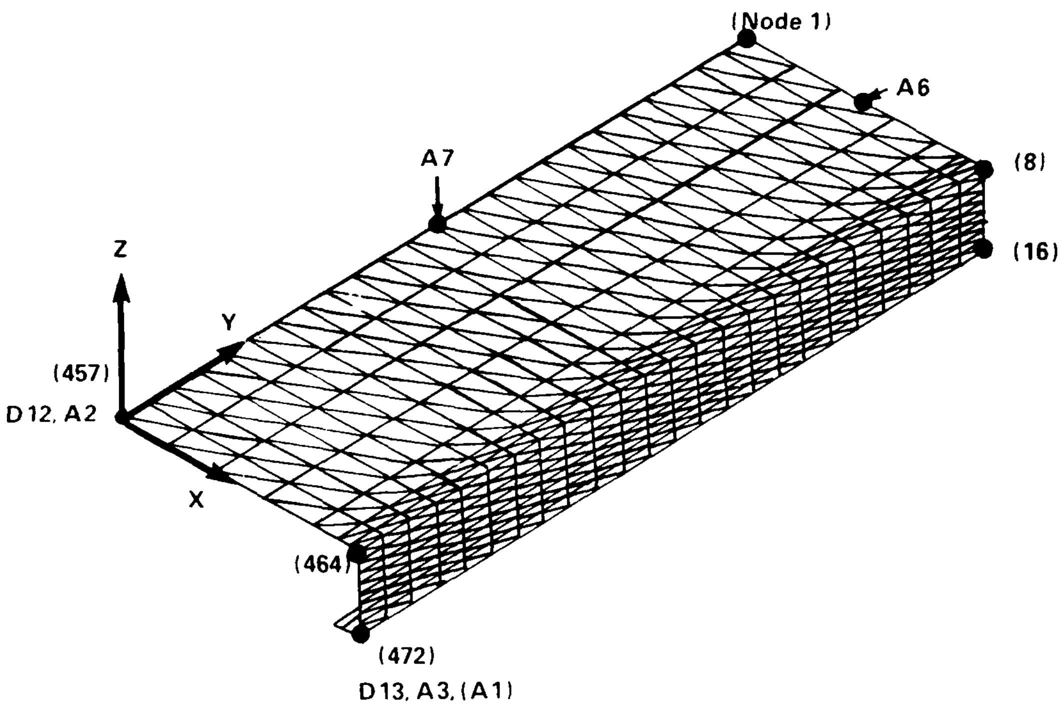
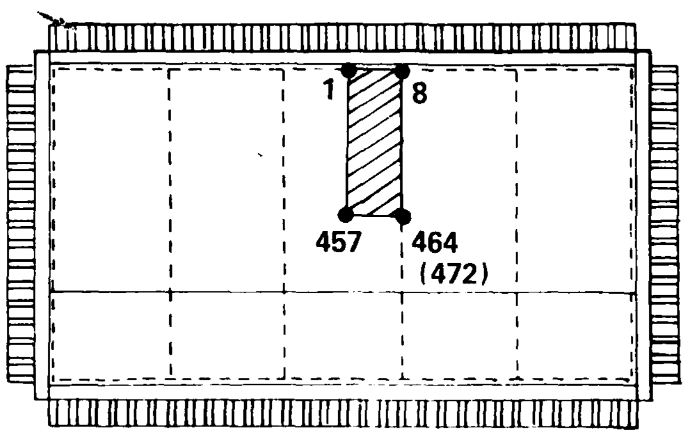


Figure 19

MEASURED STRAIN-TIME HISTORIES FROM STRAIN GAUGES ON FRONT AND BACK EDGES OF THE PANEL



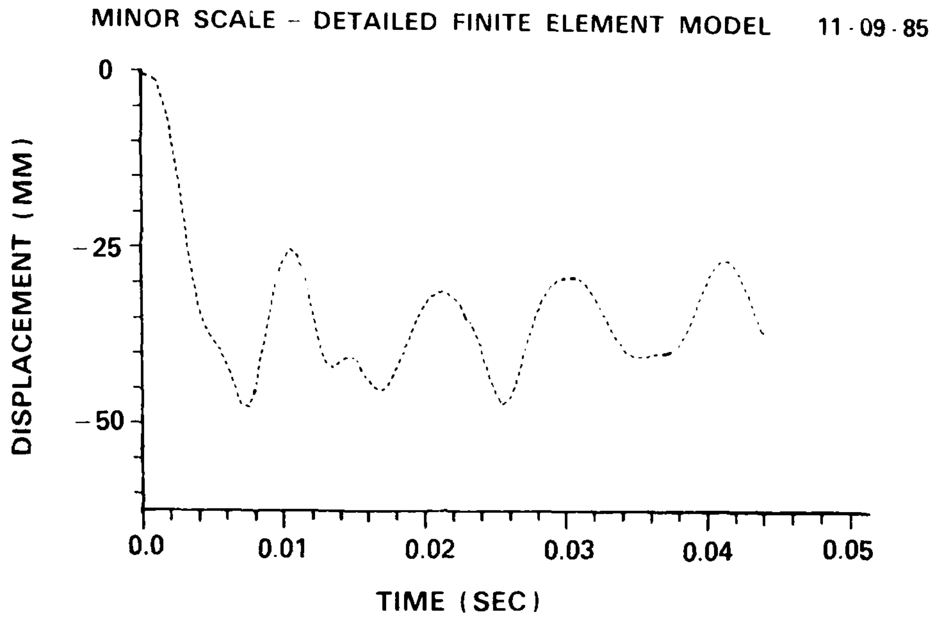
FINITE ELEMENT MODEL



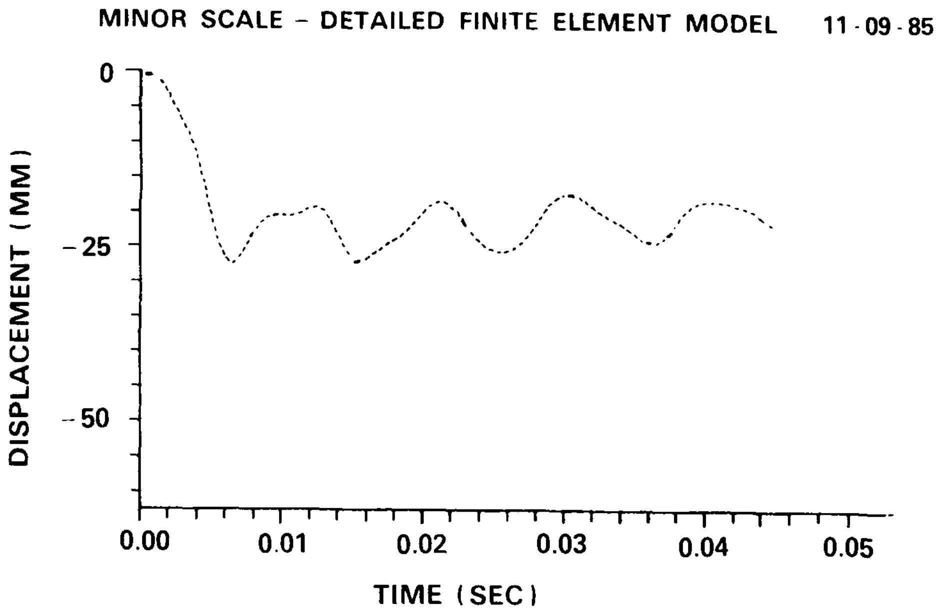
TOP VIEW

Figure 20

REFINED FINITE ELEMENT MODEL OF THE PLATE/BEAM STIFFENED PANEL SEGMENT FOR FINAL DYNAMIC ANALYSIS (MARTEC)



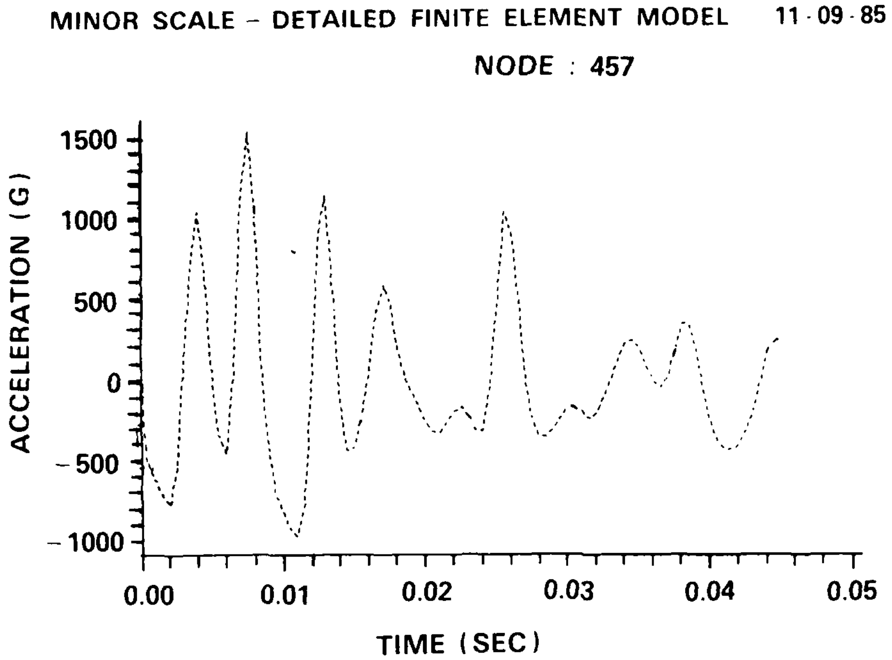
(a) CENTER OF PANEL (TRANSDUCER D 12)



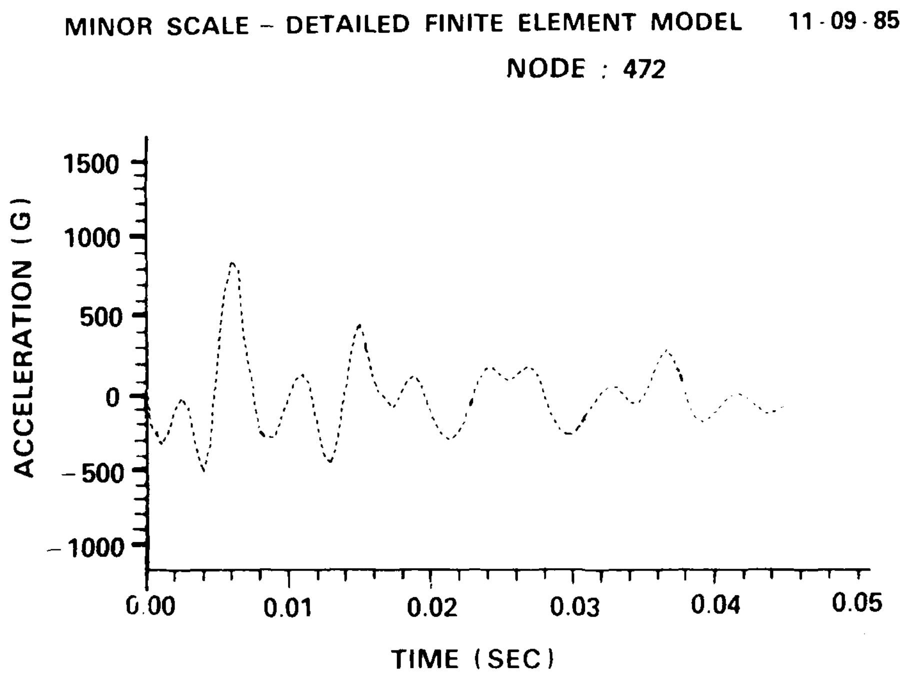
(b) MIDSPAN OF BEAM STIFFENER (TRANSDUCER D 13)

Figure 21

FINAL PREDICTIONS OF DISPLACEMENT-TIME HISTORY



(a) CENTER OF PANEL (ACCELEROMETER A2)



(b) MIDSPAN OF BEAM STIFFENER (ACCELEROMETER A3)

Figure 22

FINAL PREDICTIONS OF ACCELERATION-TIME HISTORY

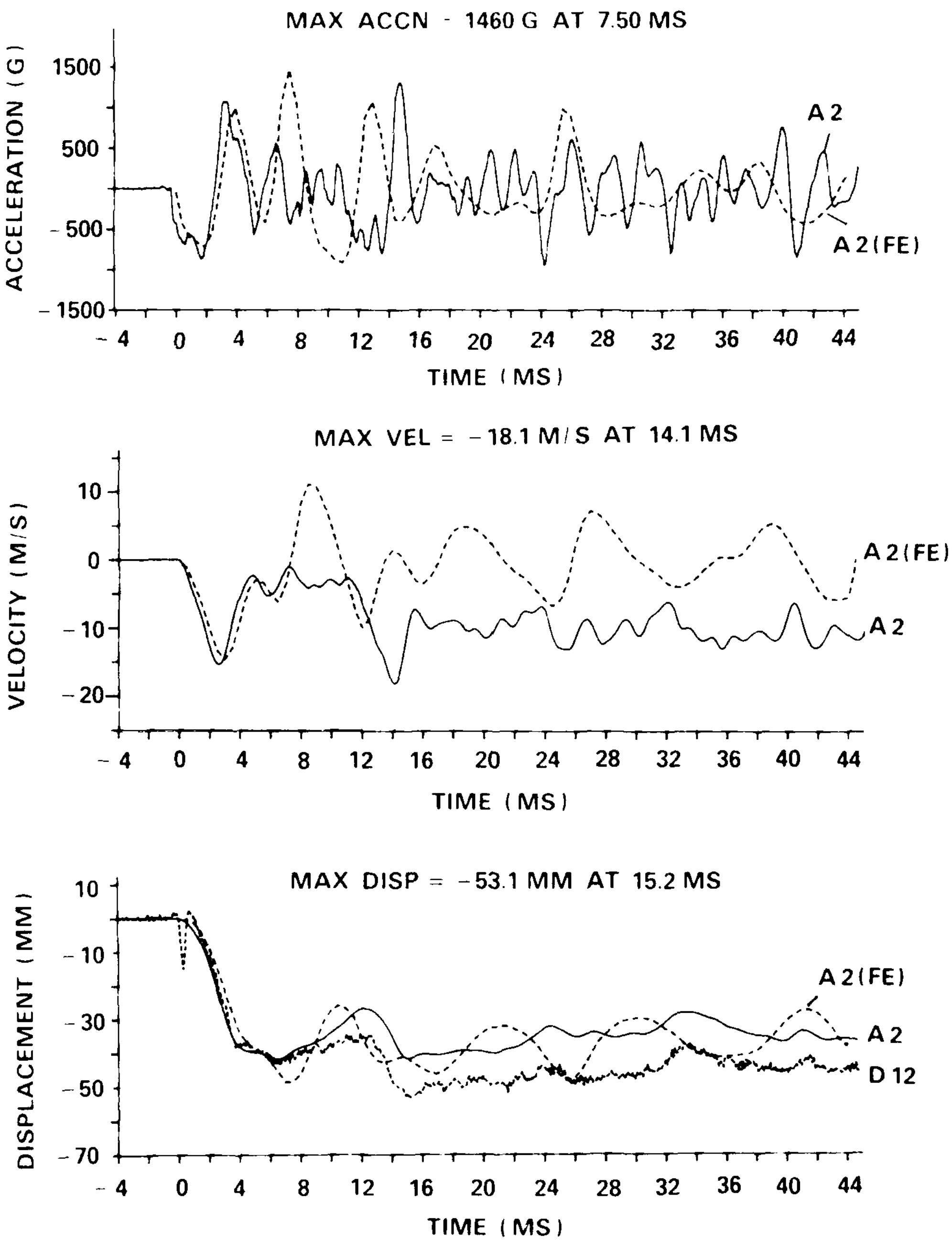


Figure 23

COMPARISON OF FINITE ELEMENT PREDICTIONS WITH THE MEASURED AND INTEGRATED MOTION-TIME HISTORY AT CENTER OF PANEL (TRANSDUCERS A2 AND D12)

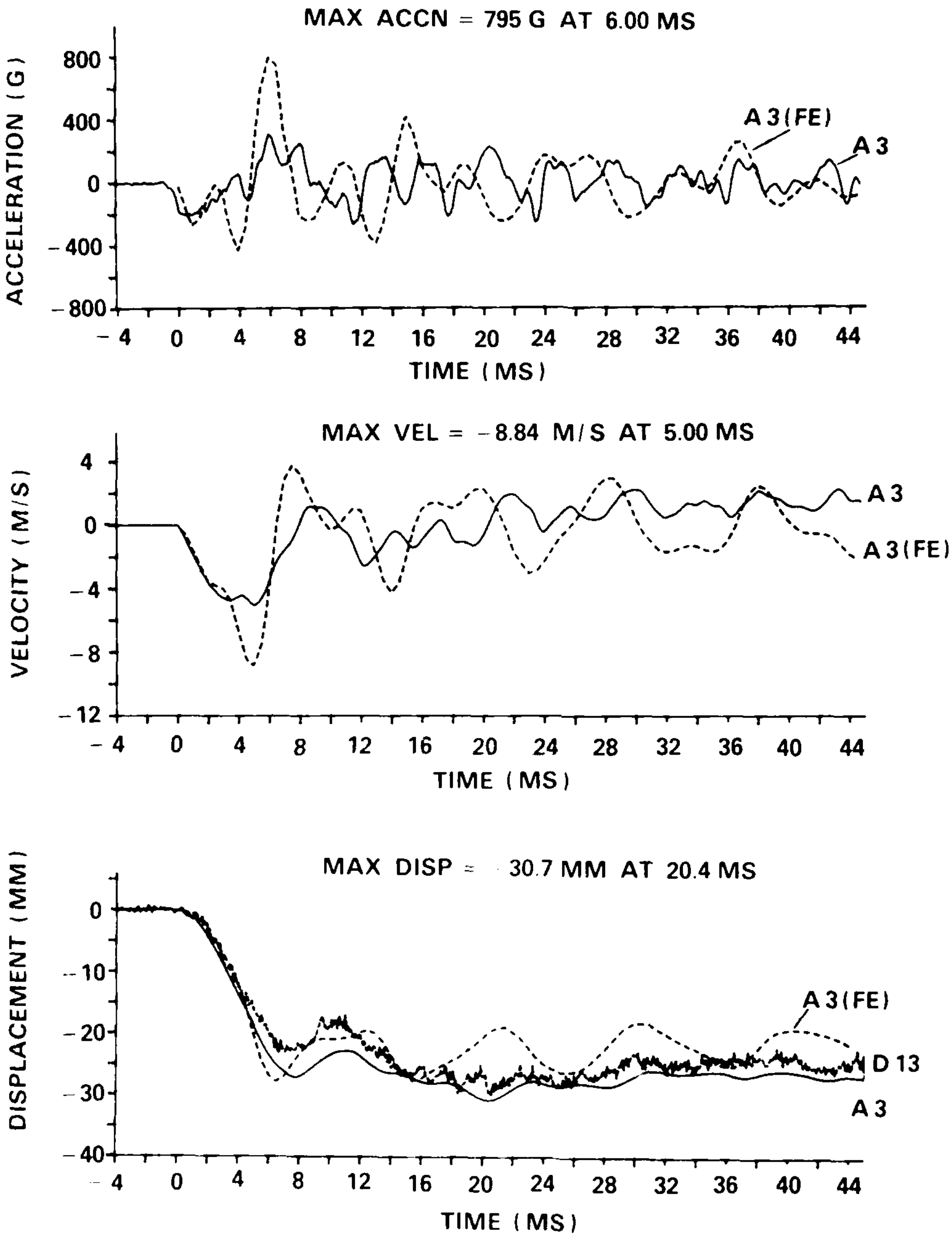


Figure 24

COMPARISON OF FINITE ELEMENT PREDICTIONS WITH THE MEASURED AND INTEGRATED MOTION-TIME HISTORY AT MIDSPAN OF BEAM STIFFENER (TRANSDUCERS A3 AND D13)

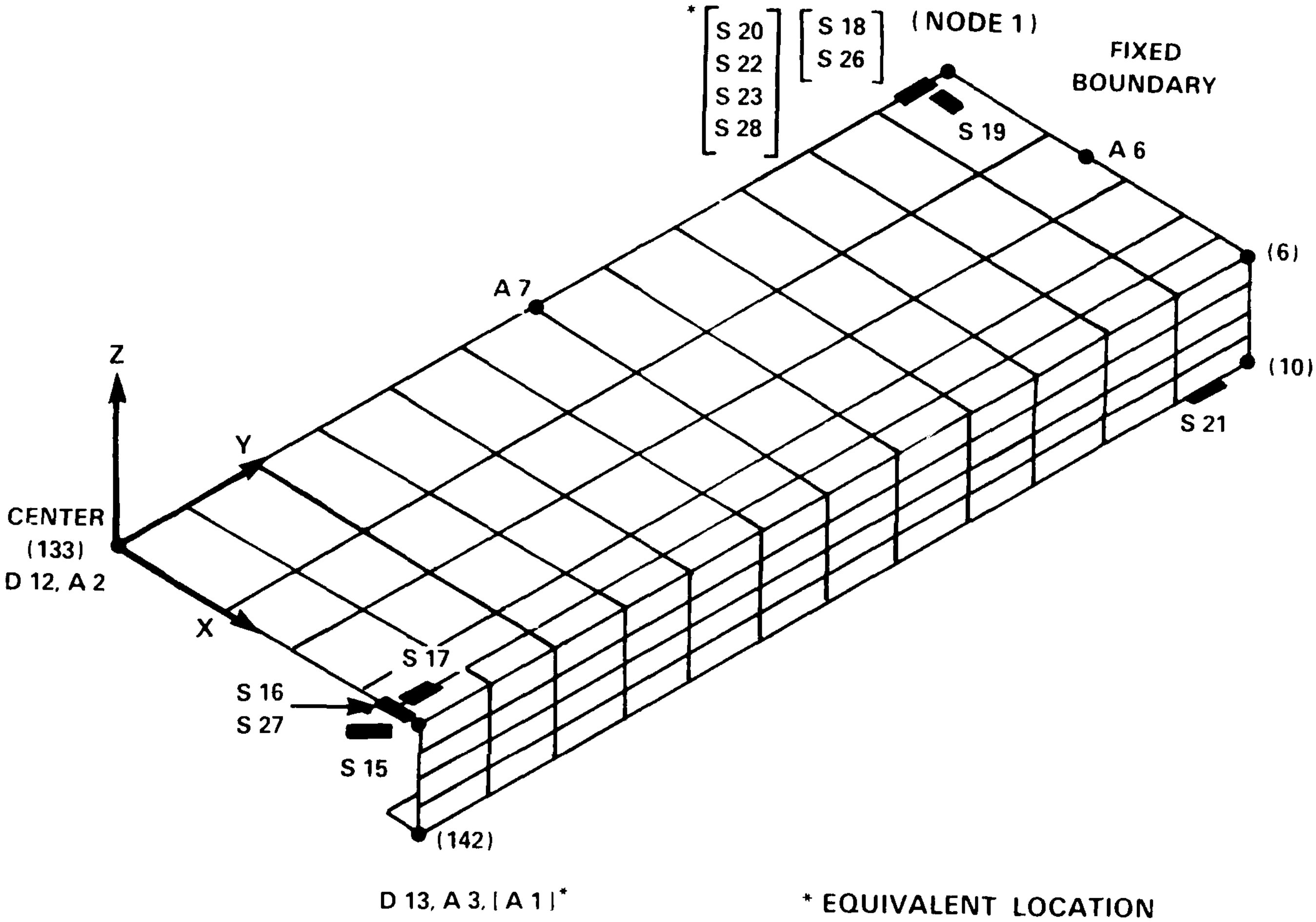


Figure 25

DRES FINITE ELEMENT MODEL USING QUADRILATERAL ELEMENT

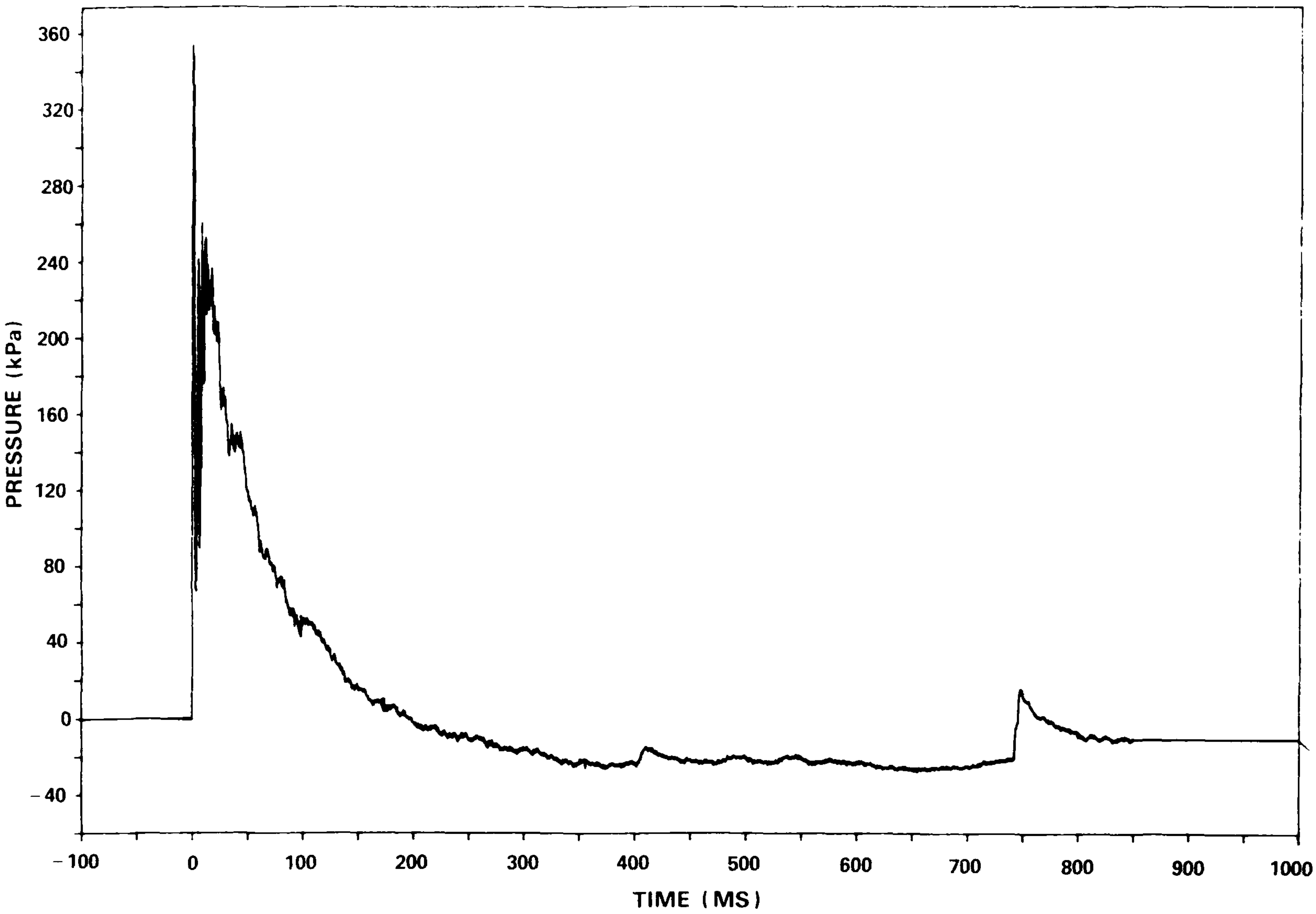
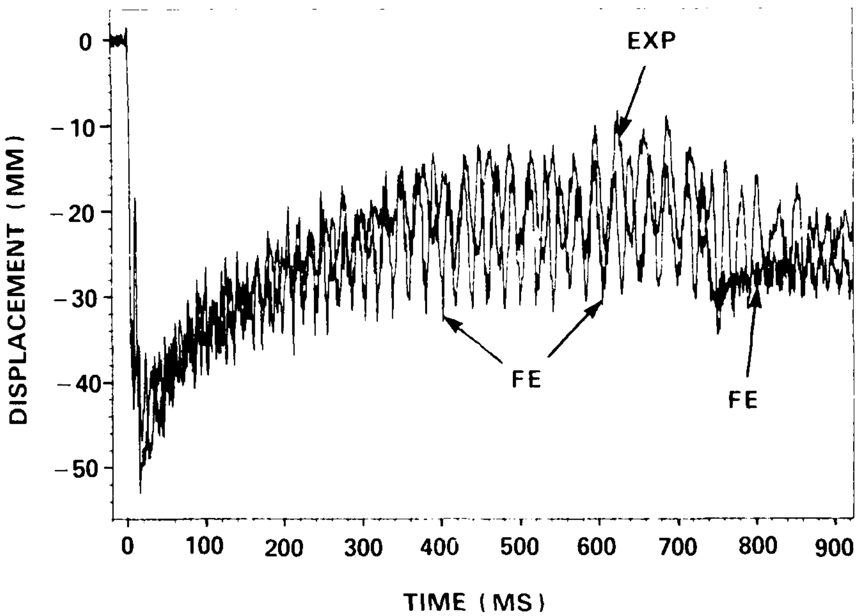
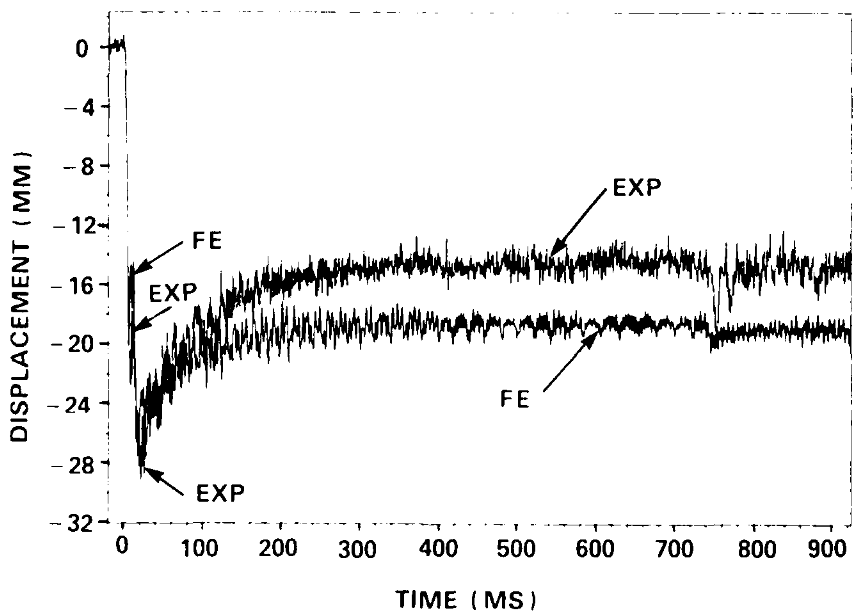


Figure 26

AVERAGED PRESSURE LOADING FROM P 1 AND P 3 FOR DRES FINITE ELEMENT ANALYSIS



(a) CENTER OF PANEL (TRANSDUCER D 12)



(b MIDSPAN OF BEAM STIFFENER (TRANSDUCER D 13)

Figure 27

COMPARISON OF FINITE ELEMENT ADINA RESULTS WITH MEASURED DISPLACMENT-TIME HISTORY

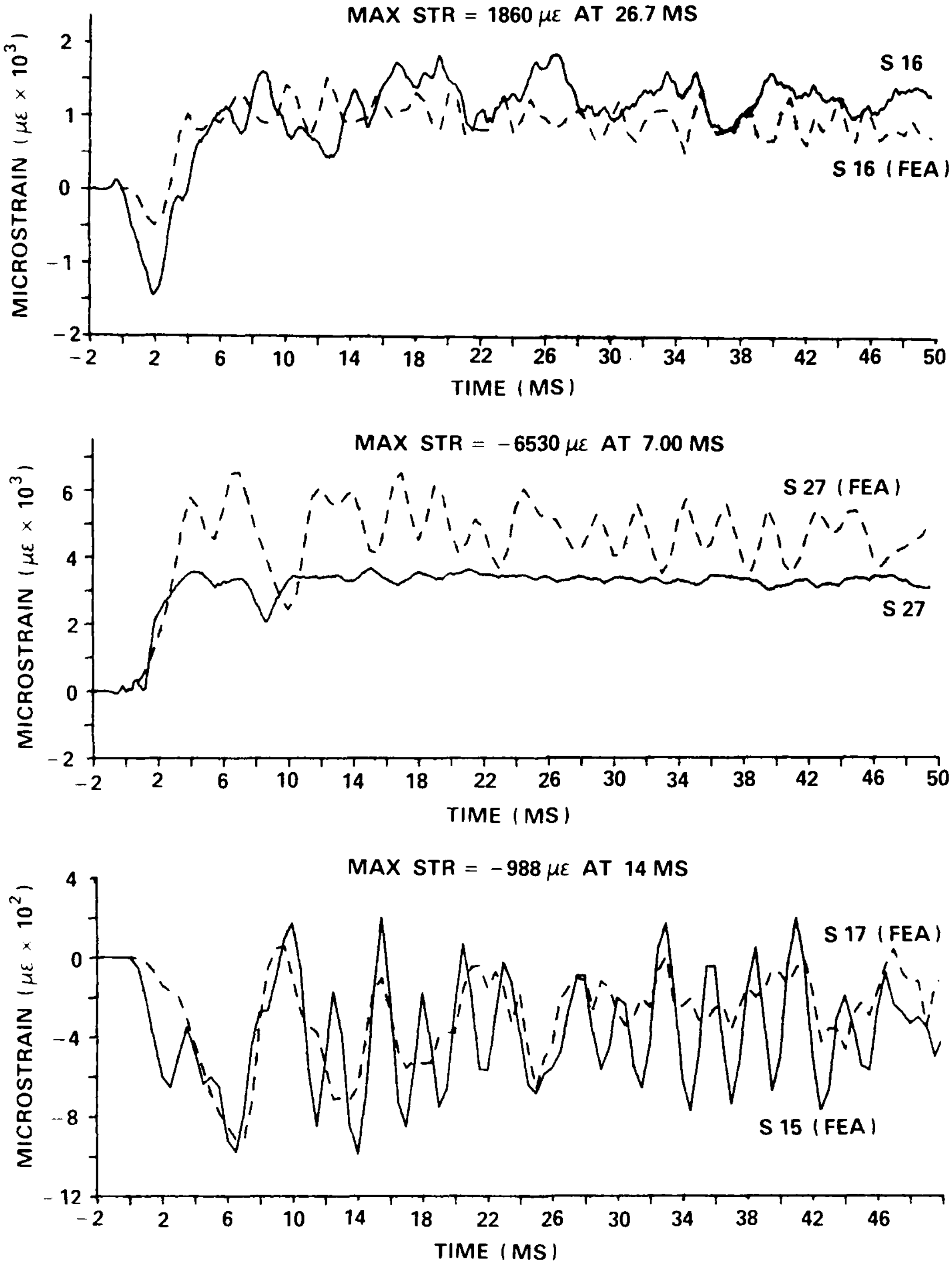


Figure 28

COMPARISON OF FINITE ELEMENT ADINA RESULTS WITH MEASURED STRAIN-TIME HISTORIES ON PANEL NEAR BEAM MIDSPAN

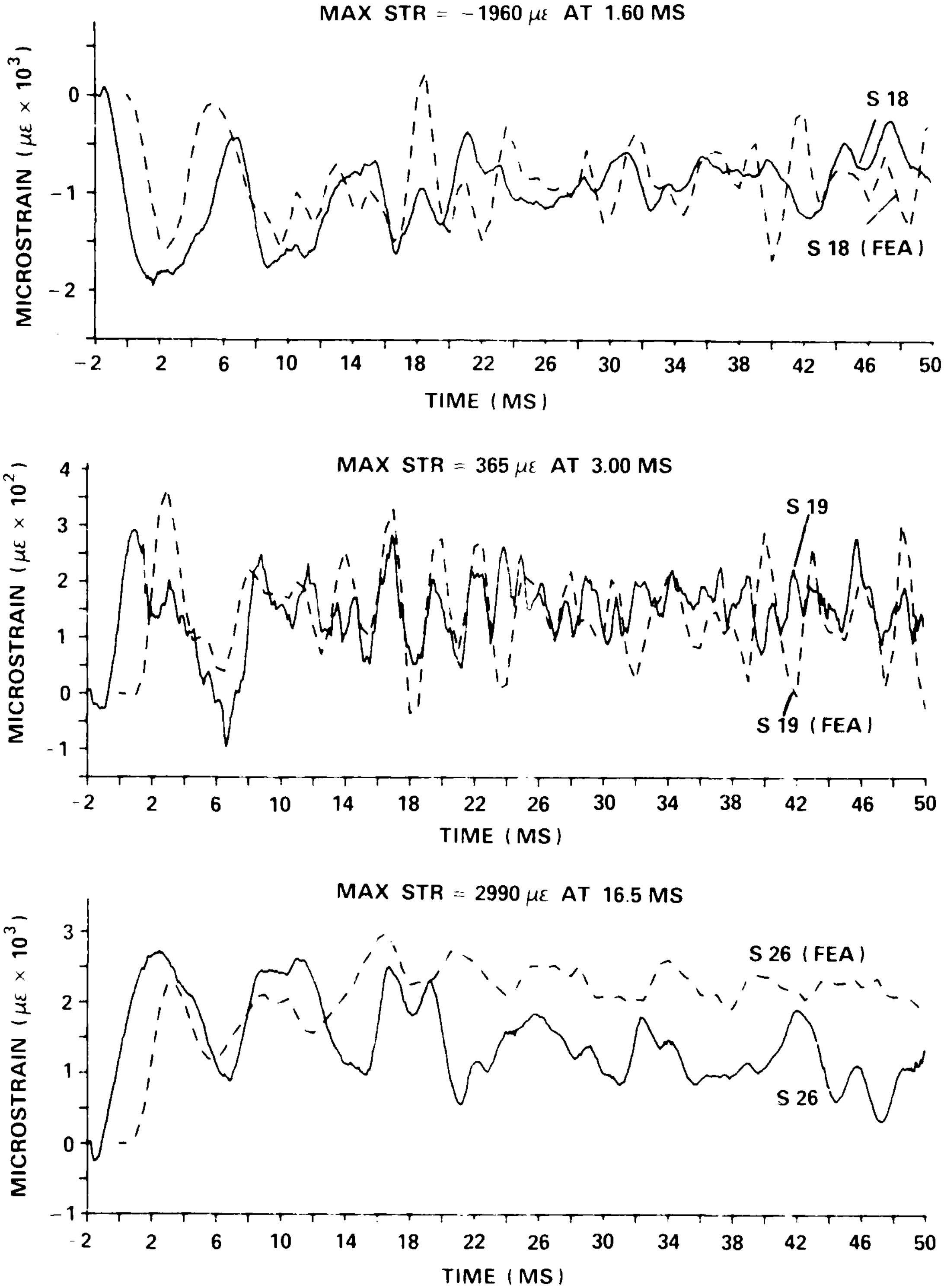


Figure 29

COMPARISON OF FINITE ELEMENT ADINA RESULTS WITH MEASURED STRAIN-TIME HISTORIES ON PANEL NEAR CLAMPED BOUNDARY

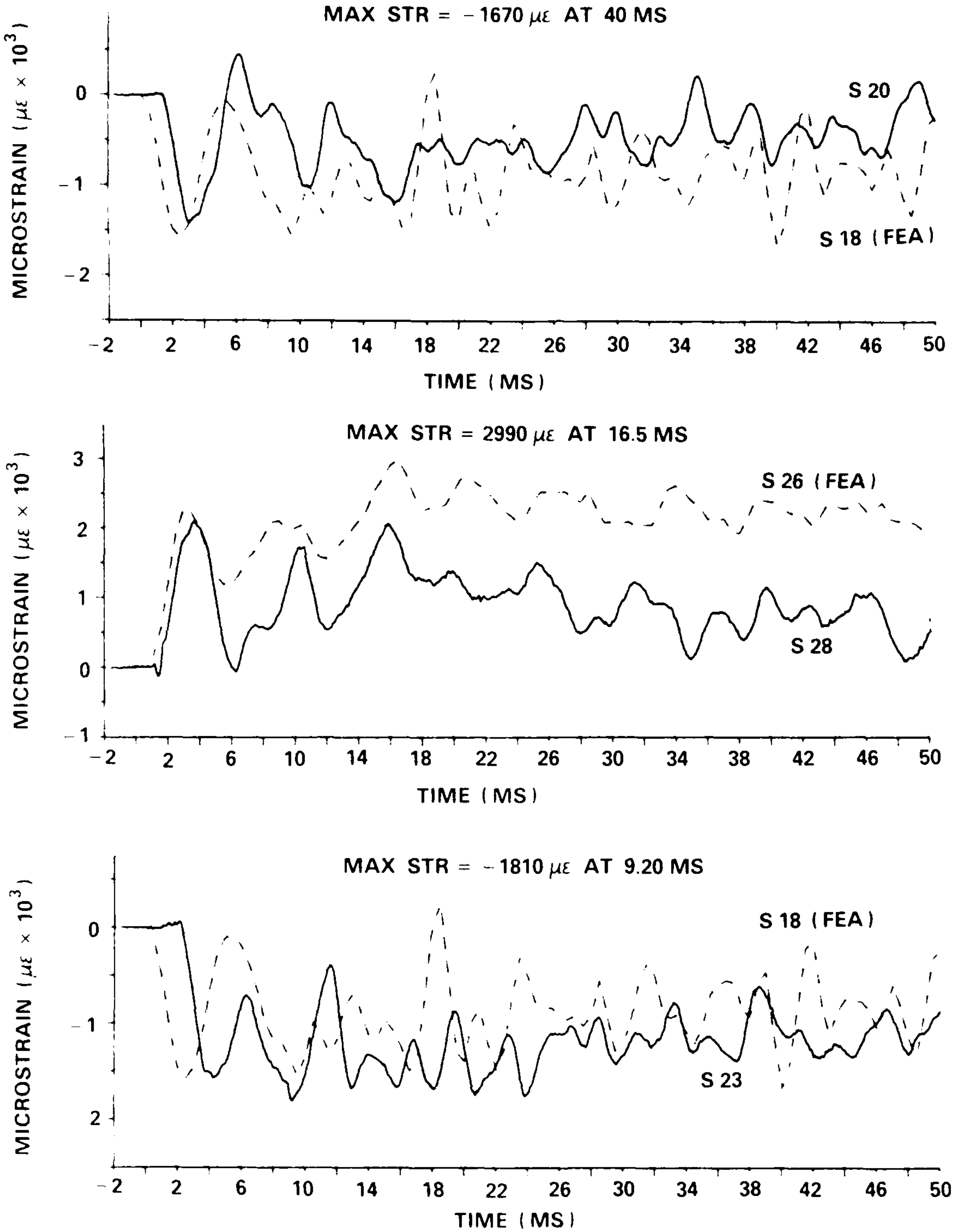


Figure 30

COMPARISON OF FINITE ELEMENT ADINA RESULTS WITH MEASURED STRAIN-TIME HISTORIES ON PANEL NEAR CLAMPED BOUNDARY EQUIVALENT TO GAUGE LOCATIONS S 18 AND S 26

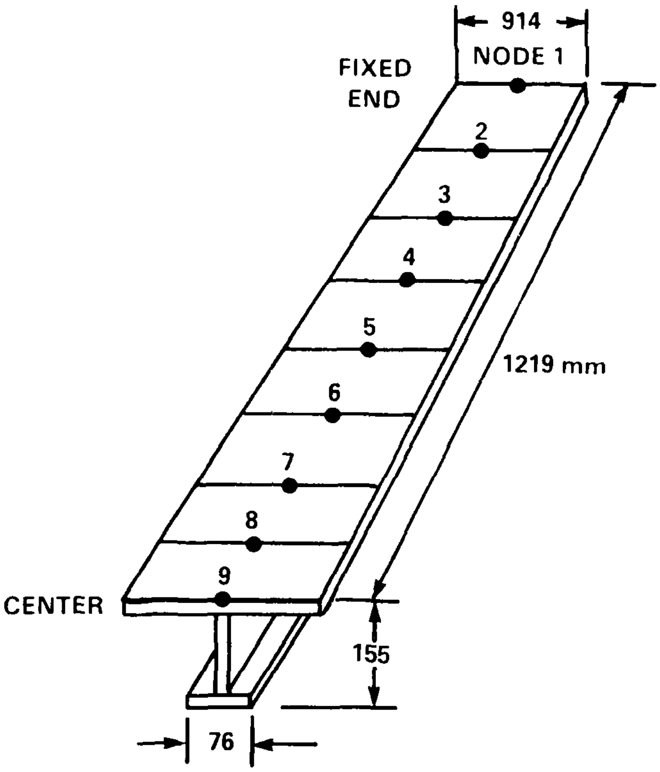


Figure 31a

FINITE ELEMENT EQUIVALENT BEAM MODEL OF STIFFENED PANEL FOR FENTAB

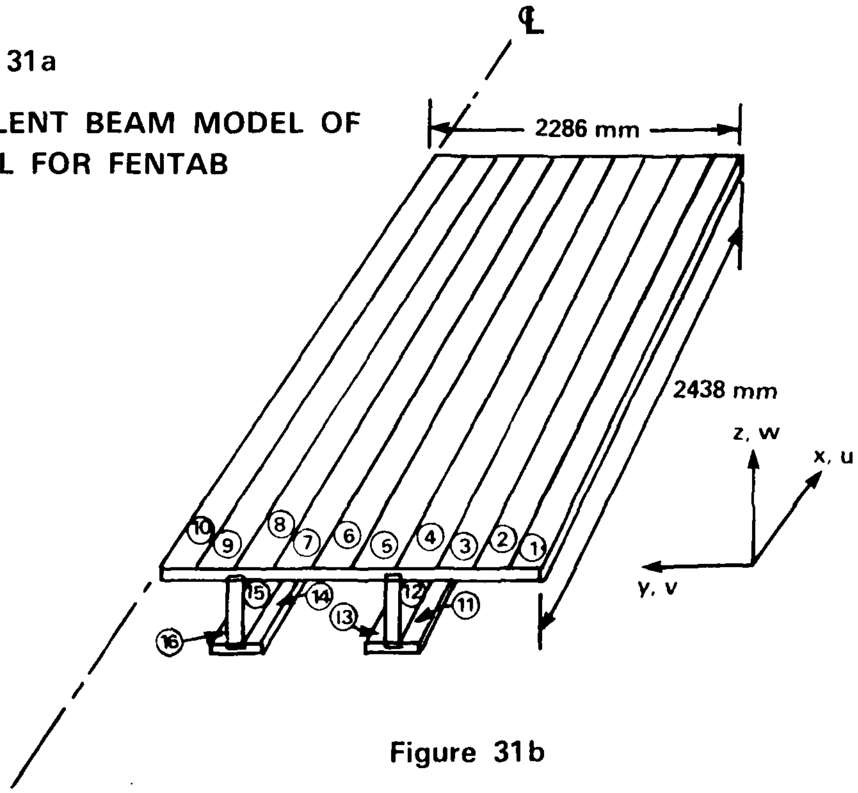
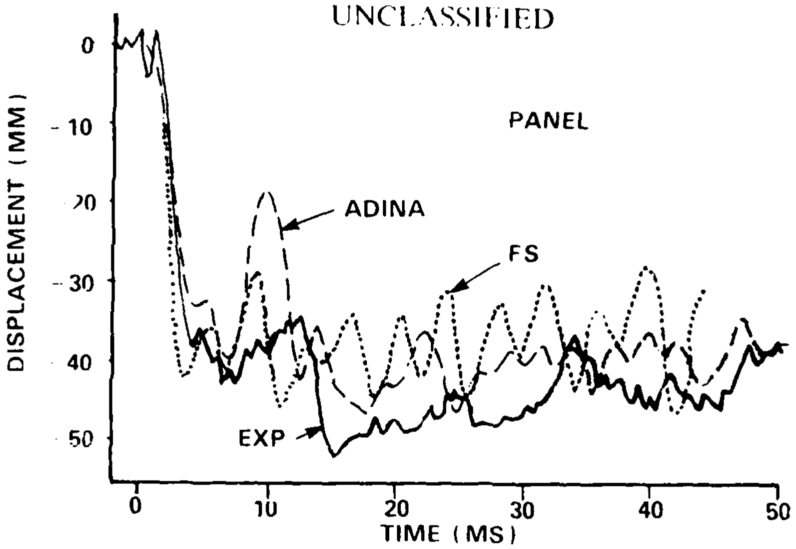
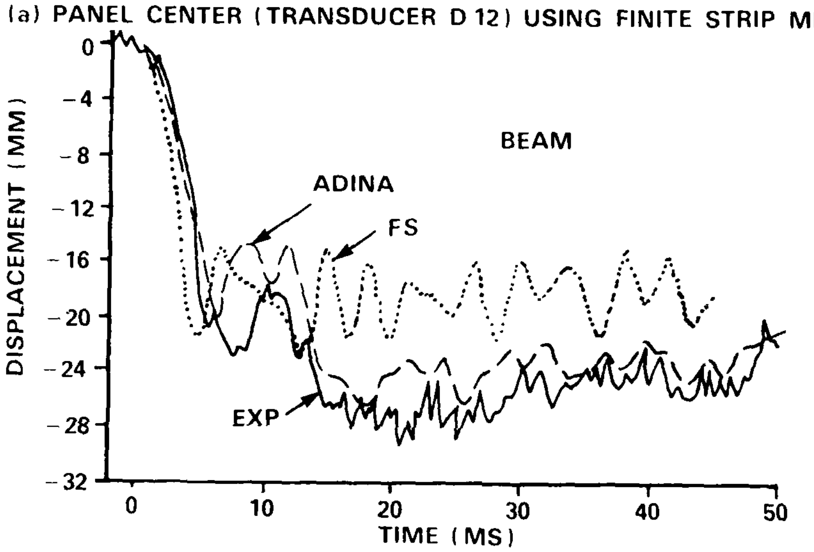


Figure 31b

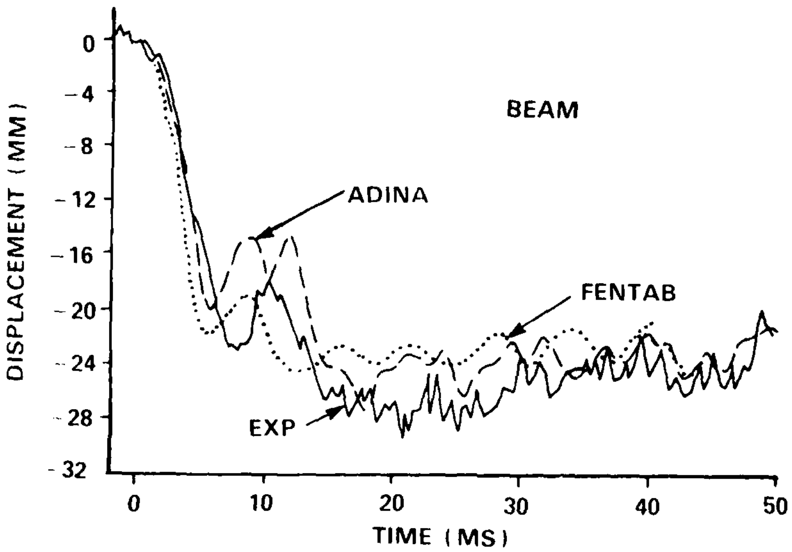
FINITE STRIP MODEL OF STIFFENED PANEL



(a) PANEL CENTER (TRANSDUCER D 12) USING FINITE STRIP METHOD



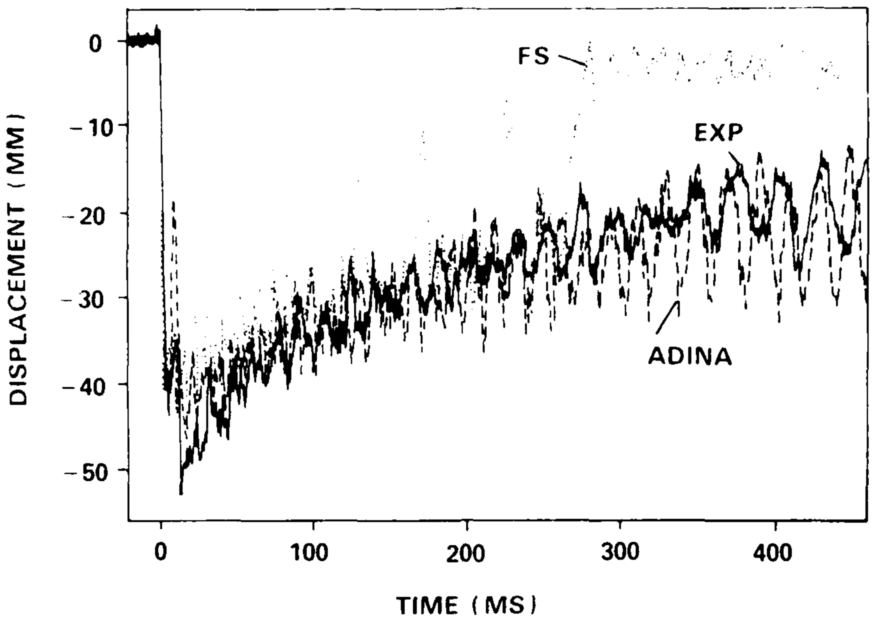
(b) BEAM MIDSPAN (TRANSDUCER D 13) USING FINITE STRIP METHOD



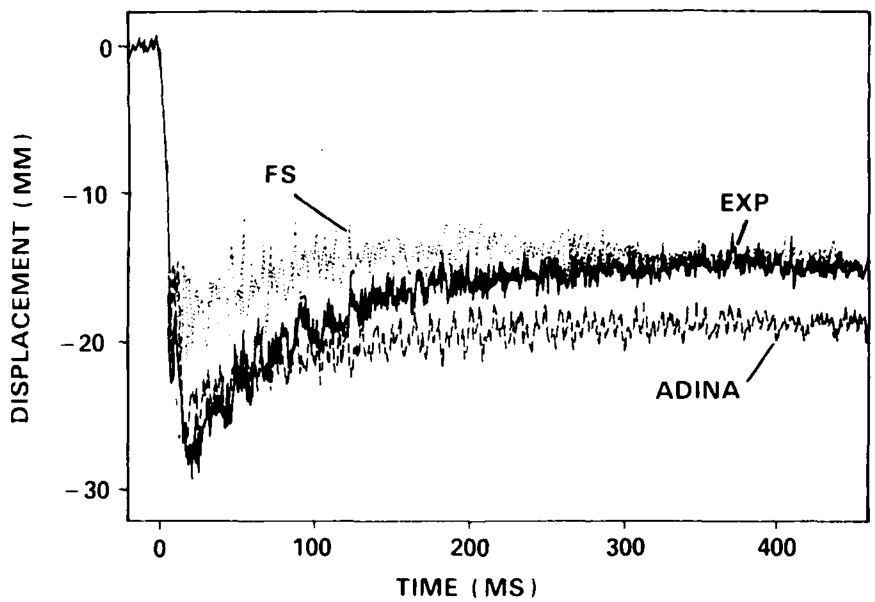
(c) BEAM MIDSPAN (TRANSDUCER D 13) USING FINITE ELEMENT EQUIVALENT BEAM METHOD FENTAB

Figure 32

COMPARISON OF UBC NUMERICAL PREDICTIONS WITH ADINA RESULTS AND MEASURED DISPLACEMENT-TIME HISTORY



(a) PANEL CENTER (TRANSDUCER D 12)



(b) BEAM MIDSPAN (TRANSDUCER D 13)

Figure 33

COMPARISON OF THE FINITE STRIP PREDICTIONS WITH ADINA RESULTS AND MEASURED DISPLACEMENT-TIME HISTORY

UNCLASSIFIED
This Sheet Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1 ORIGINATING ACTIVITY Defence Research Establishment Suffield Ralston, Alberta TOJ 2NO	2a. DOCUMENT SECURITY CLASSIFICATION unclassified 2b. GROUP

3 DOCUMENT TITLE

STRUCTURAL RESPONSE OF SHIP STIFFENED PANEL AT EVENT MINOR SCALE (U)

4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Suffield Report No. 485 (1984-1987)

5 AUTHOR(S) (Last name, first name, middle initial)

Slater, J.E., Houlston, R. and Ritzel, D.V.

6 DOCUMENT DATE January 1988	7a. TOTAL NO. OF PAGES 65	7b. NO. OF REFS 38

8a. PROJECT OR GRANT NO. 0311R	9a. ORIGINATOR'S DOCUMENT NUMBER(S) SR 485
8b CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10 DISTRIBUTION STATEMENT

UNLIMITED

11 SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY Task for Director Maritime Engineering Support National Defence Headquarters, Ottawa

13 ABSTRACT

Modern computational methods and experimental test procedures are being developed to determine more accurately the air-blast loading and dynamic response of naval ship structures subjected to weapon explosions. Previously, a series of air-blast trials on full-scale stiffened panels typical of those used in warship superstructures had been conducted for conventional scale weapons (under 454 kg HE) to evaluate new design and damage-assessment techniques. The present report describes the experimental results and the associated numerical study of the panel response for a longer duration loading generated by the simulation of a 8 kiloton nuclear weapon surface explosion called MINOR SCALE. The panel, exposed to a side-on overpressure blast loading of 345 kPa peak and 200 msec positive duration, experienced only slight permanent deformation of about 25 mm with no apparent weld or buckling failure. The measured pressure, strain, acceleration and displacement data correlated well with the computed numerical results, thus verifying the computational methods.

DSIS
78-070

UNCLASSIFIED

This Sheet Security Classification

KEY WORDS

Structural Response
Air-Blast
Panel(s)

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the organization issuing the document.

2a. DOCUMENT SECURITY CLASSIFICATION: Enter the overall security classification of the document including special warning terms whenever applicable.

2b. GROUP: Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3. DOCUMENT TITLE: Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6. DOCUMENT DATE: Enter the date (month, year) of Establishment approval for publication of the document.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the document.

8a. PROJECT OR GRANT NUMBER: If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b. CONTRACT NUMBER: If appropriate, enter the applicable number under which the document was written.

9a. ORIGINATOR'S DOCUMENT NUMBER(S): Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S): If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT: Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this document from their defence documentation center."

(2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines, 7½ inches long.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.

END
DATE
FILMED
5-88
DTIC